A FIRST BOOK OF
RURAL SCIENCE

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2 FEB 1914
266

MACMILLAN AND CO., LIMITED
ST. MARTIN'S STREET, LONDON
1913

FIRST BOOKS OF SCIENCE

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20 FEB 2008

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PREFACE.

Most of the subject matter of this little book formed part of a course of lessons given by the author, first to farmers' sons of sixteen years of age and upwards attending Winter Agricultural Classes, and later to pupils in the upper forms of rural Secondary Schools. In preparing this book the requirements of these two classes of students have been kept chiefly in view.

The aim has been to provide an elementary course on the science of crops and soils that will interest the pupils and be helpful in farm practice. Each of the scientific facts discussed is shown to be related to operations and phenomena which are familiar to every boy living in the country.

Much of the work has also been found useful as a Nature Study subject for boys in the higher classes of rural Elementary Schools. The study of soils, and of plants of agricultural importance, is at least of equal value as a means of developing the intelligence as the study of plants and animals which are not of economic value to the farmer. No disability, therefore, is inflicted upon boys who do not subsequently follow rural occupations; while, to the majority of pupils, the knowledge thus gained will be much more useful in after life, and will lead to a better appreciation of the facilities offered for "further" education at Farm Institutes and Agricultural Colleges.

The practical work given at the beginning of each chapter is designed to enable the students to find out, by obser-

vation and experiment, the main facts discussed in the descriptive text. The text, however, is complete in itself, and where the suggested practical work cannot be done before reading the chapter it should be done afterwards in preference to the "practical exercises" given at the end of the chapters.

For pupils already engaged in farm work who are attending Farm Schools or Evening Continuation Schools, practical work in school, although desirable, is less necessary than in the case of pupils who have not had the opportunity of gaining practical experience of agriculture. The former class can better appreciate the references to practical farming given in the text, and they have greater opportunities of making observations on the farm. In these circumstances some of the practical work could be done with advantage as class-room experiments by the teacher.

Included in the questions given at the end of each chapter are many that have been set at the examinations of the Board of Education in Agriculture and Rural Economy.

All but five of the illustrations in the book are new. I am indebted to Miss H. M. Lusty for the drawings, and to Mr. H. Crofts, M.Sc., for taking photographs of all the soil experiments illustrated. Photographs have been kindly placed at my disposal by Mr. J. L. Duncan, B Sc. (Fig. 41), Messrs. Garton (Figs. 17 and 18) and Mr. G. Ryce, B.A. (Figs. 44 and 45).

My sincere thanks are also due to Mr. H. B. Tilley, B.Sc., for assistance in reading the proofs, and to Professor R. A. Gregory and Mr. A. T. Simmons, B.Sc., for their valuable help at all stages in the preparation of the book.

J. J. GREEN.

COUNTY AGRICULTURAL LABORATORIES,
EXETER, *December*, 1912.

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CHAPTER I.

SEEDS: STRUCTURE AND GERMINATION.

PRACTICAL WORK.

1. Soak seeds of broad beans or peas overnight in water, and examine them next day. With the aid of a penknife, remove the tough skin and make drawings, natural size, of the parts shown in Fig. 1 as you see them in your specimen.

2. Place a number of soaked bean or pea seeds between the folds of a piece of damp white flannel on a deep plate. Cover with a similar plate turned upside down, and keep the flannel moist in a warm room. Examine the seeds each day, and, when they commence to sprout, make drawings every second day of the same seed. What changes take place in the radicle, plumule, seed leaves, and seed coat?

When the plumule has emerged from between the seed leaves, cut off the latter from some of the young plants, and compare their subsequent development with the uncut seeds.

3. Sow mustard seeds on damp blotting-paper laid on a plate. Cover the seeds with another plate to prevent the paper drying. Keep the seeds moist in a warm room. The seeds are thus supplied with water, warmth, and air. Compare the germination with other seeds kept under exactly similar conditions, except that (*a*) one lot is kept dry, and (*b*) one lot is kept at a low temperature, say in the open air—if in winter.

Are water and warmth necessary for germination?

Place mustard or wheat seeds in a bottle full of water which has been boiled and cooled, and cork tightly. Compare

the subsequent growth with another lot of the same seeds kept moist only. Place the bottles side by side in the same room. Is air necessary for the sprouting of seeds?

4. Germinate mangel or beet "seeds" on damp blotting-paper. How many plants grow from each "seed"? Cut and examine the "seeds," and determine why.

5. Take 50 oat grains, and remove the husks from half of them; now germinate the 50 grains, and find out if the removal of the husks interferes with germination.

Structure of seed.—When a dry bean, or pea, seed is soaked in water for a day or two, it swells and becomes soft; and the structure is then made out readily with the aid of a penknife.

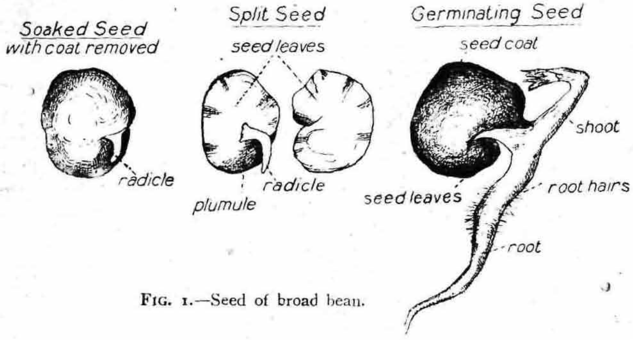

FIG. 1.—Seed of broad bean.

Outside the seed is a tough skin, termed the **seed coat,** having a black scar on one side, which marks where the seed was attached to the pod. On removing the seed coat, the **radicle** is seen as a projecting cone. The seed easily splits lengthwise into two fleshy lobes termed **seed leaves,** or **cotyledons,** attached, on opposite sides, to the base of the radicle. Lying between the seed leaves and continuous with the radicle is the **plumule.**

If the seed is sown in moist sawdust and kept in a warm room for a few days, it will sprout. The radicle pushes

through the seed coat, grows downwards, and becomes the **root**; and, later, the plumule emerges between the seed leaves, grows upwards, and develops into the **shoot**.

The radicle, plumule, and seed leaves constitute the **embryo**, or young plant, which in the bean occupies the whole of the cavity enclosed by the seed coat.

Function of the seed leaves.—The bean seed is usually sown from 3 to 4 inches deep, and the shoot has to make its way through this depth of soil before the young plant is able to obtain its food from the soil and air. In the meantime it is dependent upon the supply of food stored in its thick seed leaves.

In the bean, the seed leaves remain below the surface of the ground, and their work is done when their food store is absorbed. In the mustard, as in the bean, the embryo fills up the seed coat; but the two seed leaves not only contain food material to provide for the first growth of the young plant, but are carried above ground by the growth of the stem, become green, and serve as ordinary foliage leaves. They are known as the "smooth leaves," as distinguished from the rough leaves which appear later. In the turnip, which is similar to mustard, it is these smooth leaves which are so liable to be destroyed by the turnip-flea beetle. If this occurs before some of the rough leaves have expanded, the plant will be killed.

Seed leaves which come above ground differ in appearance from ordinary foliage leaves, and only live for a short time.

Wheat seed.—In the grain of wheat (Fig. 2) the embryo may be seen at the base of the grain, opposite the furrow. It occupies only a small part of the seed. The remainder of the seed is filled with nutriment for the development of the embryo when germination takes place. The embryo has only one seed leaf: on germination three roots arise from the radicle.

Where, as in wheat, mangel, and all corn and grass seeds, the food reserve is stored *outside* the embryo, it is termed **endosperm.**

The reserve material in wheat and beans consists chiefly of starch, and in mustard of oil.

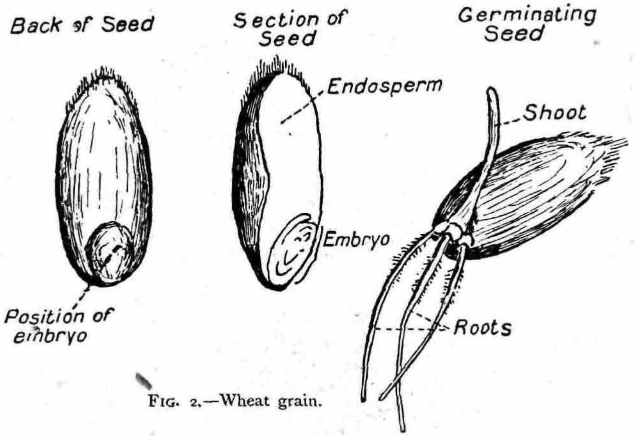

FIG. 2.—Wheat grain.

Parts present in all seeds.—Whilst seeds differ in many ways they all have: (1) an embryo; (2) a store of food, either within or outside the embryo; and (3) a seed coat.

Size of seed and depth of sowing.—Large seeds have more reserve food for the nourishment of the young plant than small seeds. If a mustard seed were sown as deeply as a bean seed is usually planted, its store of food would be used up before the shoot could reach the surface, and the plant would perish. Large seeds are, therefore, sown deeper than small seeds.

Fruits sown for seed.—In many "seeds" sown by the farmer, the true seed is enclosed within other parts. What is sown for seed in these cases is, botanically speaking,

a "fruit." If a pea pod with its enclosed seeds were sown instead of the shelled peas, it would be a fruit sown for seed. The mangel "seed" (Fig. 3) is a cluster of several fruits, each containing one seed, so that several plants usually grow from one "seed." Outside the seed coat of wheat there is a very thin and closely adherent fruit wall. All corn and grass "seeds" are fruits, and, except wheat and rye, all those sown by the farmer have one or more pairs of

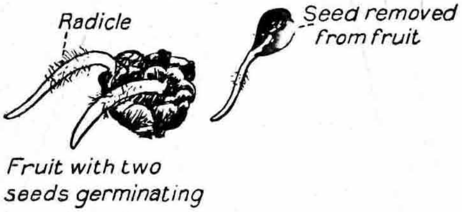

FIG. 3.—Germinating mangel "seed."

chaffy scales external to the fruit wall. In oats, for example, there is one pair of such scales loosely enclosing the fruit, and known as the husk.

Conditions of germination.—If a living seed is supplied with a sufficient amount of (1) *water*, (2) *warmth*, and (3) *air*, it will sprout or **germinate**, and develop into a seedling plant.

Dry seeds will not germinate. Seeds sown in late spring and summer often lie dormant for weeks after sowing owing to lack of moisture. A suitable temperature is necessary. Few seeds germinate below a temperature of 40° F. or above one of 110° F. Between these extremes there is a temperature for each kind of seed, at which germination proceeds most rapidly. This is usually between 70° and 100° F. Air is required to supply oxygen, without which seeds cannot germinate. While the growth of seeds in the soil is more often prevented or retarded owing to lack of water or heat

than want of air, in wet soils, or where seeds are buried too deeply, the air supply may be insufficient for the requirements of the germinating seed.

It is not sufficient for the farmer to sow his seed under conditions that will provide merely the minimum amounts of water, warmth, and air necessary for germination. In such a case growth will be slow, the seedlings sickly, and very liable to succumb to the many dangers that beset the young plant. A well prepared seed bed greatly reduces the risk of failure. Its character will depend upon the kind of seed, the nature of the soil, and the time of sowing. For example, for small seeds, such as grass and clover, the seed bed must be fine, or much of the seed will get too deep and be wasted. It must be firm or it will not keep moist. For autumn wheat, the seed bed should not be fine, but rough on the surface and consolidated below. A seed bed quite suitable for wheat in October might be disastrous for barley in March.

The conditions influencing the supply of moisture, heat, and air in the soil will be considered later.

Some causes of failure.—Consider which of the three necessary conditions are most likely to be insufficient for vigorous growth in the case of the common farm seeds. Wheat sown in early autumn is generally put in under conditions favourable to germination. From November to March, germination is often hindered owing to the coldness of the soil; or the soil may be so saturated with water that the air supply is interfered with. Hence, the seed of late sown wheat and early sown oats and barley sometimes rots in the ground. This is most likely to occur on stiff clay land.

Mangels are sown in April or early in May. The soil is then usually moist and moderately warm, and, as a rule, if the seed is good it germinates well. The chief danger is, that on clay soil a hard crust may form on the surface after

sowing. This result may be due to sowing before the land is dry enough, or to heavy rain followed by quick drying weather immediately after sowing. The caked surface, besides interfering with the air supply to the germinating seed, may be too hard for the young plumule to break through.

Turnip, grass, and clover seeds are sown in May and June. These seeds are small, and therefore must be covered lightly with soil. The temperature and air supply are generally very favourable, but the soil is often too dry for the seed to germinate. The seeds will lie dormant until rain falls, so that little harm is done. Very serious loss, however, may result if there is sufficient moisture to start germination, but not enough for growth to proceed. At this time of the year the surface soil soon dries, and the seedlings may be killed before the roots reach down to the moist soil below.

In some districts such seeds are spoken of as being "malted." In preparing malt, the barley is steeped in water and spread on the floor of a room kept at a suitable temperature. The barley germinates, and after about 12 days, growth is stopped by drying the seeds. The young rootlets are screened off, and the grain is found to have been converted into malt. Hence the term "malted" well describes what often happens to small seeds during a dry summer, or in a badly prepared seed bed.

Germination of weed seeds.—One of the methods of combating weeds is to encourage their seeds to germinate at a time when the seedlings can be destroyed easily. For example, on charlock infested land the sowing of the corn is often delayed until much of the weed is got rid of in this way. When the land is cultivated in the spring, seeds previously buried are brought to the surface. These germinate, and the seedlings are killed by harrowing, which brings more seed near the surface. These again are destroyed after germination; thus, as many crops of charlock as possible are got rid of before the corn is sown.

EXERCISES.

PRACTICAL.

1. In a garden plot sow ten seeds each of bean, wheat, and turnip, at depths of ½ in., 2 in., and 6 in. Note when the shoots appear in each case, and compare the results of sowing at different depths.

2. Put mustard seeds in boiling water for one minute. Compare the germination of these seeds with untreated seeds.

3. Make a solution of iodine by dissolving a few crystals of potassium iodide in water and adding small quantities of iodine until the solution is the colour of brown vinegar. Add a drop of this solution to a piece of starch; it turns a deep blue colour. This is a test for starch. Cut across seeds of wheat and bean and test them for starch in the same way.

4. With the side of a knife-blade squeeze a flax seed (linseed) on to a piece of white paper, and hold the mark made by the seed up to the light. Compare with the mark left on paper by a drop of oil. Test seeds of charlock and mustard for oil in the same way.

WRITTEN.

1. What conditions are necessary in order that living seeds may germinate? Which conditions are most likely to be lacking in the case of (*a*) barley sown in February, (*b*) grass seeds sown in June?

2. Loss is often caused by corn sprouting in the standing sheaves or stook. In what sort of a season is this likely to occur?

3. Make drawings of various seeds to show the different ways in which they store food for the future plant. Has the size of the seed anything to do with the depth at which it should be sown?

4. Describe experiments to show what conditions are necessary to secure the germination and growth of seeds.

5. Why are some samples of wheat more plump than others? Why should such grain produce the best plants?

6. What is meant by the cotyledons of a plant, and what is their use? Name two plants whose cotyledons come above the surface of the ground, and two where they remain below.

CHAPTER II.

SEED TESTING.

PRACTICAL WORK.

1. Count out carefully, and germinate on damp blotting-paper, 100 seeds of red clover. Examine the seeds every day, and remove and count those that have sprouted. What percentage finally germinates?

2. Some of the seeds in the previous experiment will fail to swell, and remain as hard as the dry seed. Make a scratch on these with a pin and see if they will then swell and germinate.

3. Make yourself thoroughly acquainted with the appearance of perennial rye grass seed. Obtain a handful of these seeds from a farmer or seed merchant, spread out the seeds on a sheet of clean white paper, and examine them carefully with a hand lens. Remove with forceps anything present other than the seed of perennial rye grass, and note whether it is (1) chaff, (2) some other kind of seed, or (3) dirt.

4. From a sample of red clover seed pick out 100 of the shrivelled and reddish coloured grains and 100 bright plump seeds. Germinate each lot in separate vessels kept side by side, and compare (*a*) total number germinating, and (*b*) number germinating in 4 days.

Importance of good seed.—Anything that is sown by the farmer for the purpose of obtaining a crop, he refers to as **seed,** whether it is a true seed like the bean, or a fruit as in

mangel. It is in this sense that the term *seed* will be used in the present chapter.

Commercial seed varies greatly in quality; and it is important that only seed of high quality should be bought

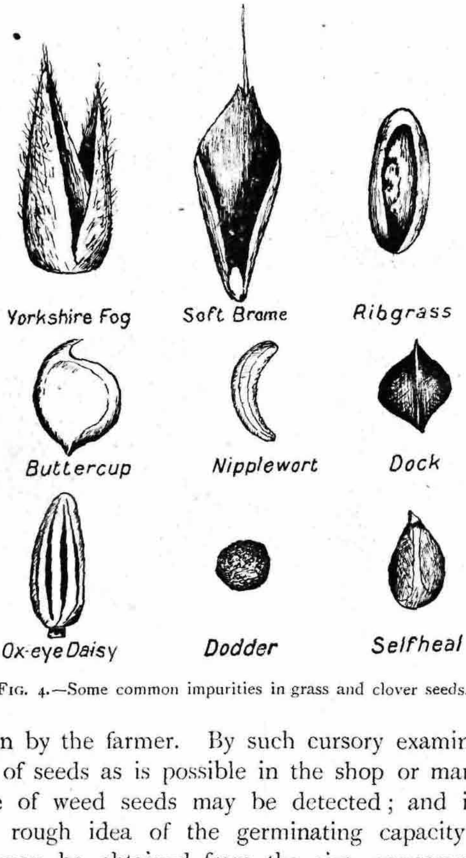

FIG. 4.—Some common impurities in grass and clover seeds.

and sown by the farmer. By such cursory examination of samples of seeds as is possible in the shop or market, the presence of weed seeds may be detected; and in many cases a rough idea of the germinating capacity of the sample may be obtained from the size, appearance, and smell of the seeds. An examination of this kind, however,

will only reveal comparatively wide differences between the samples examined, and it may even be misleading. In order to obtain trustworthy information as to the quality of seeds, they must be very carefully tested, and there are several centres in Great Britain and Ireland for testing seeds for farmers at a small fee.

The points that can be determined accurately at a seed-testing station are:

1. Purity, and nature of impurities.
2. Germination.
3. Germinative energy.
4. Weight of seed.

Purity.—Everything in a sample of seed except genuine seeds, true to name, are **impurities**. The impurities may consist of:

1. **Inert material**, such as dirt and chaff, not harmful, but weighed with the seed, and therefore costing the same price.

2. **Weed seeds**, all of which are more or less harmful, and some very injurious.

3. Seeds of plants not usually regarded as weeds, but not of the kind required, *i.e.* not true to name.

Absolute purity is not expected, but seeds may be obtained practically pure. Some of the weed seeds commonly found in grass and clover seeds are shown in Fig. 4.

Germination and germinative energy.—Failure to germinate, or slowness of germination, may be due to various causes. Amongst the most common are:

1. **Age**: some seeds, *e.g.* turnips, beans, and charlock, retain their vitality longer than others, such as wheat and red clover; but all seeds ultimately die. Age is usually indicated by shrivelling of the coat and by change of colour. Where the true seed is hidden from view by other parts, as in mangel and grass seeds, this change of colour is not seen.

2. **Immaturity**: unripe seeds germinate badly, or not at all.

3. **An unfavourable harvest**: in a wet or damp season, seeds may start growth in the field or stack before thrashing; such seeds will not sprout again.

4. **Overheating in stack**: this also is most likely to occur after a wet harvest.

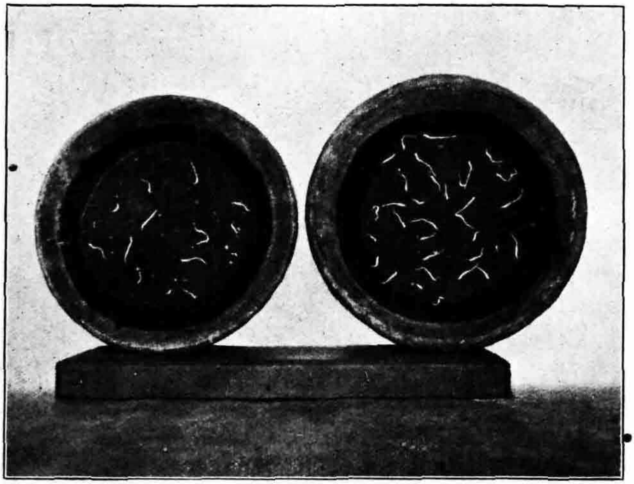

FIG. 5.—Photograph of good and bad clover seed after 4 days' germination: 50 seeds on each saucer.

Good seeds germinate rapidly. The mere statement of the maximum percentage of germinating seeds gives no idea of the vigour of the embryo, and the likelihood of strong healthy plants resulting from their growth. Hence, the percentage of seeds germinating in a given time—when the conditions are under strict control—is determined and is known as the **germinative energy**. This cannot be done where there is no means of regulating the temperature; but samples of the same kind of seed may be correctly

compared when kept under the same conditions. That is to say, the germinative energy of a sample tested at 50° F. cannot be compared with that of a sample tested at 70° F. The samples can only be compared if both are tested at 50° F. or at 70° F. At seed-testing stations the seeds are germinated in an incubator maintained at a definite temperature for each kind of seed. The usual times allowed for the determination of the germinative energy are:

Clover, wheat, barley and turnips -	3 days.
Mangel, rye grass, timothy, meadow fescue	5 ,,
Oats and carrot - - - - -	6 ,,
Dogstail, foxtail and cocksfoot - -	7 ,,

Fig. 5 is a photograph of two samples of germinating red clover seed taken after being for 4 days in an incubator kept at 68° F. There are 50 seeds in each saucer. Both were purchased in the same district, and particulars are given in Exercise 3 (p. 18).

Hard seeds.—Samples of clover and other seeds belonging to the same family usually contain a number of seeds that fail to swell until the seed coat has been scratched. They are known as **hard seeds.** Although the embryo is living and capable of germination, it will not germinate until the hard seed coat is broken, to allow of water being absorbed. Hard seeds are of little value to the farmer; but when testing clover seeds, the percentage present is usually determined.

True value.—Suppose that a sample of cocksfoot has a purity of 90 % and a germination of 50 %. This does not mean that out of 100 lbs. of seed 50 lbs. will grow; but that in 100 lbs. of commercial seed 90 lbs. are seeds of cocksfoot, and of these, 50 %, *i.e.* 45 lbs., or 45 % of the original seed, will germinate under proper conditions. This is the percentage of pure *and* germinating seed, and is known as the **true value.**

If P is the percentage of purity and G the percentage of germination Then:

$$\frac{P \times G}{100} = \text{true value.}$$

Substituting values of P and G in above example, we have:

$$\frac{90 \times 50}{100} = 45.$$

A knowledge of the "true value" of seed enables the farmer to compare the relative cheapness or dearness of the seed he buys, and to calculate the quantity of different samples of seeds of the same kind required to sow an acre.

Other things being equal, the price should be in direct proportion to the "true value."

EXAMPLE.—A farmer is offered two lots of cocksfoot seed: A having a "true value" of 72 % at 11d. per lb., and B having a "true value" of 90 % at 1s. per lb. Which is the cheaper? If A is worth 11d. per lb., then B is worth:

$$\tfrac{90}{72} \times 11\text{d.} = 1\text{s. } 1\tfrac{3}{4}\text{d.}$$

As B can be bought at 1s. per lb. it is the cheaper seed, though costing more per lb. than A.

The amount of seed required per acre is in inverse proportion to the "true value"; that is to say, the higher the true value, the less seed is required.

EXAMPLE.—If clover seed having a "true value" of 92 % is sown at the rate of 10 lbs. per acre, what quantity of clover seed having a "true value" of 46 % must be sown in order to supply the same number of pure and germinating seeds per acre?

Result: $\tfrac{92}{46} \times 10 = 20$ lbs. per acre.

Such methods of comparing the value of seeds must not be applied too rigidly. Differences in the nature of the impurities and in the germinative energy must also be

taken into consideration, and such important points in seed-valuing as its pedigree and country where grown cannot be determined by testing.

Weight.—We have seen in Chapter I. that large seeds are likely to do better than small. The largest seeds will weigh most. Samples are compared in this respect by finding the weight of, say, 1000 seeds.

Method of testing.—A complete and accurate test of a sample of seeds can only be carried out by expert botanists having a knowledge of the different weed seeds, and provided with proper apparatus. The method described below is suitable for testing seeds in a school or at home, and although the results obtained may differ somewhat from those obtained at a seed-testing station, they will be quite useful for comparative purposes.

Purity.—A representative sample of from 50 to 200 grams, according to the size of the seed, is taken from the bulk. This sample is thoroughly well mixed and divided with a knife or ruler into two parts. One of these parts is mixed and halved again, and the process repeated until a small sample of from one to five grams is obtained. This is weighed on a chemical balance, and is then scattered in a line on a large sheet of stiff white or black paper, according to the colour of the seed. Commencing at the lower end of the row of seeds, each seed is examined and moved down if it is true to name, or to one side if an impurity. The line of seeds is thus worked through until all have been examined and passed or rejected. The impurities are then weighed and the percentage of purity calculated.

EXAMPLE.—Red clover seed.

Weight of seed - - -	2·125	grams.
,, impurities - -	0·105	,,
Pure seed - - - - -	2·020	,,

$$\% \text{ of purity} = \frac{2\cdot020}{2\cdot125} \times 100 = 95\ \%.$$

Nature of impurities.—The nature of the impurities is determinined by examining not only the impurities that have been removed from the small sample, but those present in the large sample. The impurities should be stated in the order of relative abundance, thus:

Dock, ribgrass, other weed seeds.

Germination.—To test germination, 100 or 200 of the *pure* seeds separated from the sample are taken. They may be germinated on damp blotting-paper as described in Chapter I., or in the arrangement shown in Fig. 6. Here the seeds are laid on damp blotting-paper in an unglazed earthenware flower-pot saucer, which is stood in a vessel of water. The

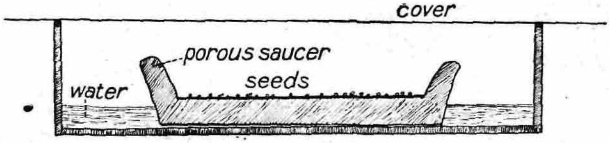

FIG. 6.—Diagram of apparatus for germinating seeds.

water must not be above the level of the blotting-paper. Sufficient water is absorbed to keep the paper moist. A plate is placed over the seeds to guard against undue evaporation.

The seeds should be kept in a warm room, and fresh air supplied by removing the plate at least once a day. Each day, the seeds that have sprouted strongly are removed and counted. In clovers the number of "hard" seeds should be noted.

EXAMPLE.—Two hundred seeds of red clover taken.

Germinated in 4 days - -	120 = 60 %.
,, ,, 12 days (final) -	184 = 92 %.
Hard seeds - - - -	8 = 4 %.

A statement of the number of seeds germinating in a given time is only of value if the samples compared are germinated in vessels kept under the same conditions.

Weight per Thousand.—To compare the size of seeds a convenient number is weighed, and the weight per thousand calculated.

EXAMPLE.—Weight of 200 seeds = 0·390 grams.

" " 1000 " = 1·950 "

Complete Report.—The complete report on the sample of red clover seed tested would be:

Purity - - - - 95 %.

Nature of impurities: Dock, ribgrass, other weed seeds, dirt.

Germination - - - 92 %.
Germinative energy (4 days) 60 %.
True value - - - 87·4 %.
Weight per 1000 - - 1·950 grams.

EXERCISES.

PRACTICAL.

1. In summer and autumn collect the seeds of common weeds found in fields, and preserve in small bottles for future reference.

The most important to secure are: Yorkshire fog, soft brome, dock, ribgrass, and buttercup.

2. Test and report on samples of seeds in the manner described in this chapter. If you don't know the names of the weed seeds present, merely state "weed seeds."

3. Obtain good samples of seeds of wheat, red clover, and turnip seeds, and test a portion for germination. Preserve the bulk in bottles, and repeat germination tests each spring. Note the effect that age has upon germination in each case.

4. Examine with a hand lens, and make drawings of, the common grass and clover seeds used on the farm.

WRITTEN.

1. Mangel "seeds" may be purchased with a guaranteed germination of 160 to 200 %. Explain how this is possible.

2. What is the "true value" of the following samples of seed which were examined at a seed-testing station :

Seed.	Purity %.	Germination %.
Red clover	97	70
" "	98	13
Italian Rye-grass	100	82
" "	98	47
Timothy	99	98
"	87	68
Cocksfoot	97	52
"	99	77

3. The following are the particulars relating to the clover seeds shown in Fig. 5.

	Purity %.	Germination %.	Price per lb.
A (to left)	95	31	8d.
B (to right)	98	88	1s.

Find the true value of each. If B is worth 1s. per lb., what should A be worth? How many lbs. of A would be required to supply the same amount of pure and germinating seeds as 10 lbs. of B?

4. A sample of clover seed was found to contain 2 % of seeds of ribgrass. In one lb. of ribgrass seed there are about 400,000 seeds. If the clover seed were sown at the rate of 10 lbs. per acre, what number of seeds of ribgrass would be sown per acre?

5. Using seed germinating 95 %, a farmer usually sows 10 stones of barley per acre. Owing to a wet harvest his seed barley only germinates 55 %. How much should he sow per acre in order to supply the same number of germinating seeds? Take it that in each case the seeds are pure.

6. What causes may influence the germinating capacity of seed?

7. Why is it important that the farmer should buy and sow good seeds? Explain briefly how you would find out which was the better of two samples of seed.

8. Explain what is meant by the terms "hard seeds," "germinative energy," and "real value."

9. Why is large seed usually better than small? Explain how you could compare the size of the seeds in three samples of turnip seed.

CHAPTER III.

THE ROOT AND SHOOT.

PRACTICAL WORK.

1. Saturate with water the soil round a bean plant. Then dig it up carefully and wash away the soil from the roots. Notice the main, or tap, root and its branches arising in vertical rows. How many rows are there? Do you find young roots interspersed between older roots, or are the younger roots nearer the tips of the older roots? Make a drawing of the root.

2. Put a cylinder of blotting-paper so as to fit inside a tumbler. Damp the blotting-paper and place a few seeds of wheat and mustard between the blotting-paper and the side of the tumbler about half-way down; cover, and set aside in a warm place to germinate. Examine the young seedlings and notice the root hairs. From what part of the root do the hairs arise?

3. Remove the cover from the tumbler in Expt. 2 and keep a little water in the bottom. Make a series of sketches showing the gradual development of the seedlings of mustard and wheat until the growth ceases.

4. Examine the stem of broad bean. Note that the tip is surrounded by immature leaves. There are also buds, or branches (developed buds) on the side of the stem; where do they arise with respect to the leaves?

5. Pull up a tuft of any long grass (*e.g.* cocksfoot). Can you distinguish the main stem? Look for buds just above the points where the lower leaves are joined to the stem.

We have learnt that during its germinative stage the young plant feeds upon the food stored in the seed by the parent plant. If the plant is to have an independent existence, the root, stem, and leaves must be well developed before all the reserve food has been used up.

The root.—The radicle of the embryo grows downwards into the ground and becomes the **primary** root. From

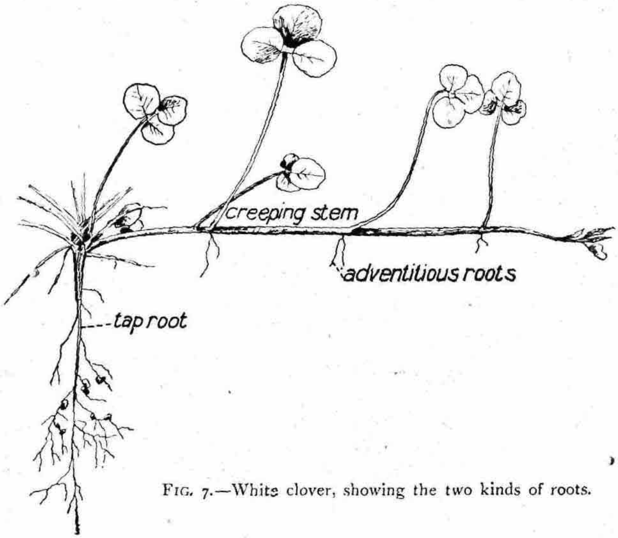

FIG. 7.—White clover, showing the two kinds of roots.

its sides **lateral** roots arise in regular order, the youngest nearest the tip. These lateral roots branch and rebranch, so that eventually a very extensive root system is developed. A primary root which has grown much larger than any of its branches is termed a **tap-root.** The bean, carrot, mangel, and many other plants, have tap-roots. Fine thread-like roots are called **fibrous roots.**

Roots may also be produced from the stem. In white clover, for example, there are two kinds of roots (Fig. 7).

The radicle of the embryo forms a long tap-root with numerous branches. The stem grows along the ground and produces roots at the points where the leaves arise. These, and all roots not produced in regular order on older roots, are called **adventitious roots.**

In wheat and all other grasses, the roots which appear on germination soon die down, and their place is taken by adventitious roots which spring from the lower part of the stem, near the surface of the ground. The roots seen on pulling up a tuft of grass are all adventitious roots. Other examples of adventitious roots are those springing from the underground stems of couch and nettle, and from the creeping stems of silver weed and strawberry. When slips, or cuttings, "strike," or take root, it is owing to the production of adventitious roots by the parts in contact with moist soil. On the stem, adventitious roots are usually produced at the joints, or nodes, where the leaves arise.

Root hairs.—On young roots, fine, silky hairs may be seen (Fig. 1). They are not found at the tip, or on the older parts of the root. These **root hairs** come into very close contact with the soil particles, and absorb water and food from the soil. This is why it is important, in transplanting, that the root hairs should be injured as little as possible.

The work of the root.—The root fixes the plant in the soil; enables it to obtain food and water from the soil; and sometimes, as in the case of mangel and carrot, is greatly enlarged, and serves as a storehouse of reserve material.

The shoot.—The stem portion of the embryo grows upwards and carries to the light the plumule, and, in some cases, the seed leaves. The leaves of the plumule expand and new leaves are produced nearer the tip of the stem. The stem and leaves together are known as the **shoot.** That part of the stem to which a leaf is attached is

usually more or less thickened, and is termed a **node**. The length of stem between two successive nodes is called an **internode**.

Buds and branching.—The shoot ends in a bud which consists of a short piece of stem with its young leaves crowded together. This is the **terminal bud**. The upper angle between the leaf stalk and the stem is called the **axil** of the leaf, and here **lateral buds** are produced.

Should these latter develop, they will grow into branches. Buds, then, are undeveloped shoots. A cabbage head (Fig. 20) is a large terminal bud. It remains undeveloped during the first season, and the following season grows into a tall shoot bearing branches and flowers.

In trees, the buds produced during the summer remain in a resting condition through the following winter, and their tightly packed foliage leaves are protected by an outer covering of scale leaves. When the bud develops in spring, the scale leaves are thrown off, and a number of small scars is left on the stem. These closely set scars form a ring, known as the **ring scar**, which marks the position of each year's terminal bud (Fig. 8). The length of stem between two successive ring scars is the result of one year's growth, and so long as these scars can be seen on a branch, or twig, its age may be determined.

Wood and fruit buds.—In fruit trees, buds which give rise to shoots bearing leaves only are known as **wood or leaf buds**; those which are to produce flowers, or flowers and leaves, are called **fruit buds**. The fruit buds of apple and pear are blunter and larger than the wood buds, and are usually borne on the end of short branches called **fruit spurs**. These fruit spurs grow very little each year, so that their ring scars are close together.

An apple tree twig as it appeared in early spring is shown in Fig. 8. The portion of the stem from the ring scar to the terminal bud grew last year, and so is one year old.

The terminal and three lateral buds can be seen. Below the ring scar is a portion of the previous year's stem (two

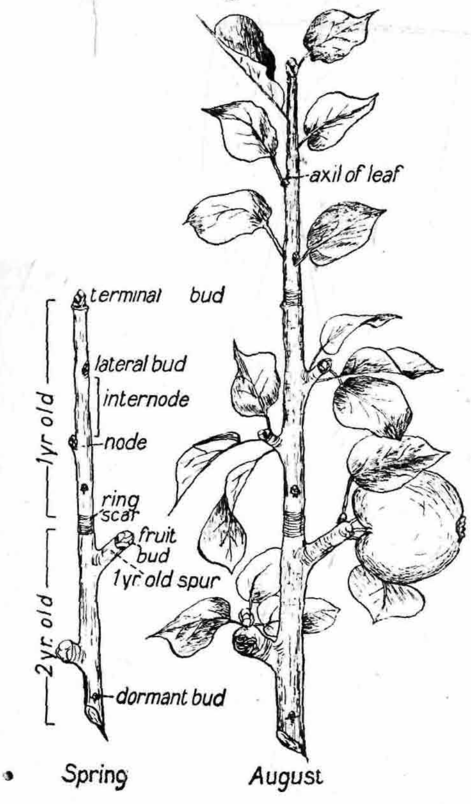

FIG. 8.—Twig of apple tree as it appeared in spring and in August.

years old). This bears two short, one year old branches, or spurs, each terminating in a thick, blunt, fruit bud.

The same twig as it appeared the following August is also shown. It has now made another season's growth and has

two ring scars. The terminal bud of the spring twig has developed into a long shoot bearing six leaves, each with a leaf bud in its axil. Two of the lateral buds have grown into short branches, or spurs; the third lateral bud has remained **dormant**. What were fruit buds last spring have evidently produced both leaves and flowers. One flower, at least, has developed into a ripe fruit, which is seen attached to one of the spurs. On the other spur are several small scars which mark the place where flowers, or immature apples, were attached.

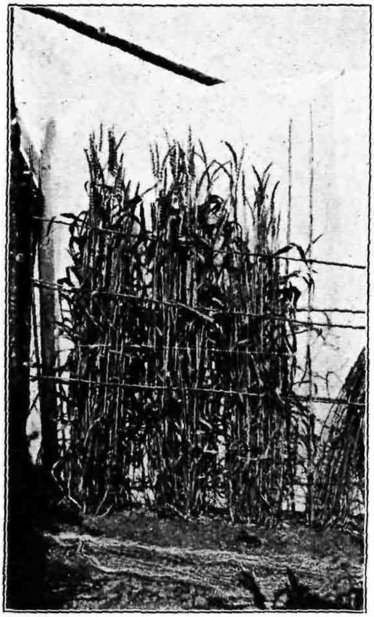

FIG. 9.—Photograph of wheat showing tillering: growth from three single seeds.

Tillering.—A wheat stem only bears buds in the axils of its lower leaves, that is, those leaves which arise near the surface of the ground. These buds at once grow out into leafy branches which in their turn may branch and rebranch in the same way. Thus, from the parent stem, a large number of branches of nearly the same age and size are produced. Later, each branch bears an ear of corn. This production of several stems from one seedling of corn is termed **tillering**. In some districts it is known as "planting" or "reeding."

This habit of branching is common to barley and oats and all grasses.

Fig. 9 is a photograph of three tufts of wheat, the product of three seeds and, therefore, of three seedlings. There are 156 stems, so that 153 "tillers" have been produced by the three parent stems.

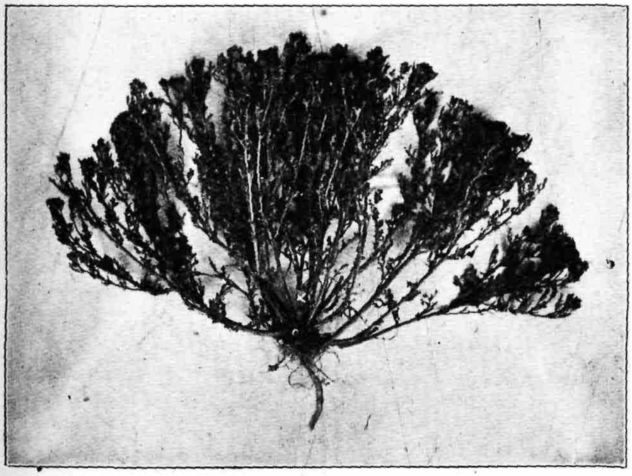

FIG. 10.—Ragwort, showing luxuriant growth due to improper cutting. Remains of parent stem indicated by X.

This exceptionally large number is accounted for by the fact that the plants were grown on rich soil with ample room. Tillering is promoted by thin sowing and good soil, and by rolling and harrowing in spring.

Dormant buds.—On the year-old portion of the apple twig as it appeared in spring (Fig. 8) there are four buds. We see that three of these developed into shoots during the summer, but the other remained latent, or **dormant.** It is not because the bud is dead that it did not develop. If the three upper buds had been destroyed,

this lower bud would have developed in the ordinary course.

Dormant buds may retain their vitality for many years. On trees, shoots which have developed from buds in their proper season are only one year younger than the stem that bears them. Dormant buds may give rise to shoots many years younger than the stem upon which they are borne.

Most plants bear a number of dormant buds which only develop if the ordinary buds or shoots are injured or

FIG. 11.—Photograph of old and neglected hedge; the lower parts of the stems are bare. Compare with Fig. 12.

destroyed. An example of this is illustrated in Fig. 10. This is a photograph of ragwort—a common weed of pastures. When well grown, the main stem was cut by the farmer, at the point indicated, with the result that on the part of the stem which remained attached to the root, dormant buds have developed into shoots; and so, in the place of the single stem, a bushy growth has appeared. Cutting in this way, instead of getting rid of the weed, only encourages it.

Adventitious buds.—Although buds usually arise in

the axils of leaves, they may also be produced from other parts of the stem, from roots, or even from leaves; such buds are termed **adventitious**. If all the ordinary buds of a plant be removed, the plant cannot live unless it possesses the power of producing adventitious buds. For example, charlock may be destroyed by cutting off its stem. The root part left in the ground has no power of producing

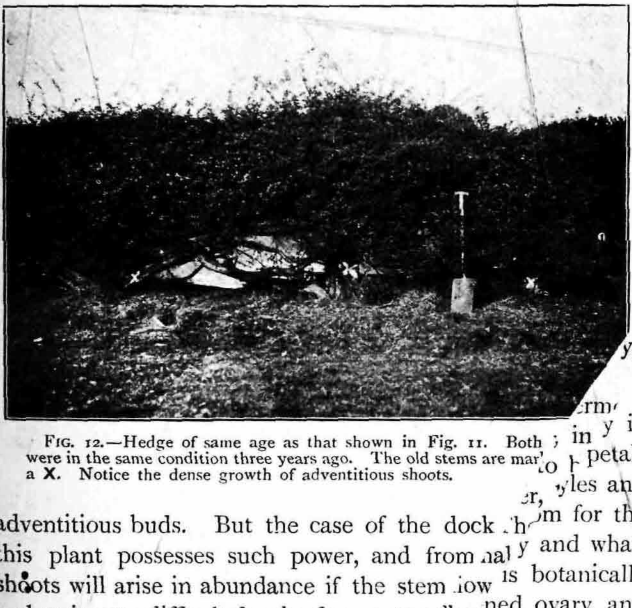

FIG. 12.—Hedge of same age as that shown in Fig. 11. Both ; in y in were in the same condition three years ago. The old stems are mar' o petals a X. Notice the dense growth of adventitious shoots. r, yles and

adventitious buds. But the case of the dock h m for the this plant possesses such power, and from al y and what-shoots will arise in abundance if the stem low is botanically makes it very difficult for the farmer to g he ned ovary, and
• A Begonia leaf pegged down on d ow
adventitious buds which grow int ries increase in size manner the cutting of trees, or bra swells and becomes the growth of numerous adven mainly of an enlarged into new shoots. Advantage e ar called the seeds are in renovation of old hedges. e a

Fig. 11 is a photograph of an old hawthorn hedge. Note the lengths of bare stems. The hedge affords but little shelter, and because it is no use as a fence against stock, the wide gaps have had to be railed across.

The hedge in Fig. 12 is about the same age and three years ago was in a similar condition. Most of the branches were removed; others were partly cut through and laid across the gaps. This drastic removal of the upper shoots has resulted in the production of a dense growth of adventitious buds on the old bare stems and branches. The trunk on the right cannot be seen for the new growth. The hedge now makes a good fence against both sheep and cattle.

EXERCISES.

PRACTICAL.

1. In winter, examine trees of apple and pear, and make out spurs, (2) fruit buds, and (3) leaf buds. Can you tell why spurs are zigzag in shape?

Examine hawthorn hedges. Can you determine from the 's, or otherwise, when the hedge was last cut?

...t the number of tillers produced by individual plants ...arley, and oats. Does the number vary from plant ...e same field, and from field to field?

...garden soil, sow, about two inches deep, three ...eat, barley, and oats respectively, with the ... When the plants are up, thin out leaving ...ach plant. When the plants are about ... the number of tillers produced by each ...e average number of tillers produced ...nd (*c*) oats respectively.

...ote that on the old parts of the ...er of very young shoots, which ...dormant or adventitious buds. ...ts on the larch, or pine.

WRITTEN.

1. What are adventitious roots? Give examples of plants on which they are found.

2. On what part of the root are root hairs found? Of what use are they to the plant?

3. What are the functions of the root?

4. How many different kinds of buds might you expect to find on an apple tree in winter? On what part of the tree are they likely to occur, and what functions are they destined to perform?

5. What are adventitious and dormant buds? Give an example of cases in which the growth of shoots from such buds is beneficial or otherwise to the farmer.

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CHAPTER IV.

THE FLOWER. PLANT BREEDING.

PRACTICAL WORK.

1. Examine the flower of charlock, cabbage, or wallflower, and make out the parts shown in Fig. 13. Remove the sepals and petals, and make a drawing of the remaining parts.

2. Obtain a specimen plant of any of those mentioned above: on the same plant will be found flowers of different ages and probably some well-grown pods. By comparing younger and older flowers, determine what part of the ...wer becomes the pod.

...What happens to the other parts?

...xamine a flower of apple, or pear, if it is available. ...that the ovary is embedded in the end of the flower ...receptacle. How many divisions are there in the ...d how many young seeds or ovules in each ... Cut vertically through the centre of a flower, ... with an apple cut through in the same ...hat parts of the flower are found in the

...—If the flower of charlock (Fig. 13), ...r be examined, the following parts

...r,

...our **sepals**. Their chief function ...of the flower. Collectively the

2. Within the sepals are four coloured **petals**, arranged in the form of a cross. Together they form the **corolla**, and serve to attract insects in search of honey.

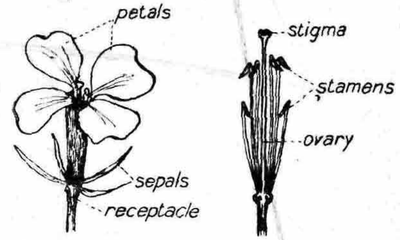

FIG. 13.—Flower of charlock. On the right, the essential parts only are shown.

3. Next in order are the **stamens**, of which there are six. The important part of the stamen is the **anther**; this is the enlarged portion at the end of the slender stalk. Within the anthers, **pollen** grains are produced, and when ripe these are set free in the form of a yellow powder by the bursting of the anthers. The stamens are the male organs of the flower.

4. In the centre of the flower is the **pistil**. Three parts may be distinguished; the enlarged portion at the base, known as the **ovary**, the slender **style** on top of the ovary, and the globular **stigma** at the end of the style.

Within the ovary are several small bodies term **ovules**, which, in y in cumstances to petals scribed later, yles and seeds. Th m for the the femal y and what- the flow is botanically

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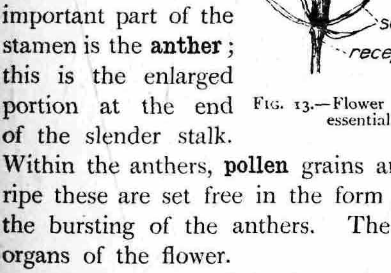

FIG. 14.—Apple flower cut down the middle.

The apple flower.—In the ar sepals, petals, and stamens are at

hollowed-out receptacle. The ovary of the pistil is completely embedded in the receptacle. The ovary has five chambers, each containing two ovules; and there are five styles—one for each division of the ovary.

Grass flowers.—The flowers of grasses are small and hidden from view within one or more pairs of chaffy leaves.

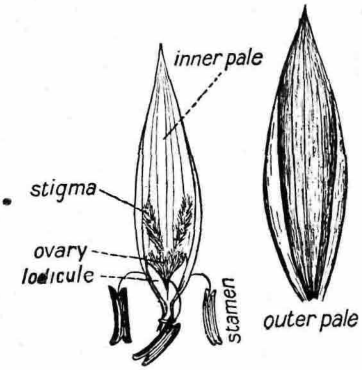

FIG. 15.—Oat flower. (×3.)

The flower of the oat is shown in Fig. 15. It is enclosed within a pair of chaffy leaves known as the **pales.** These pales are more familiar to us as the husk which surrounds the kernel in the oat grain. The flower, which is seen when the outer pale is removed, consists of a single ovary with two feathery stigmas and three stamens. At the base of the flower are two small scales, known s **lodicules,** which may represent all that is left of the als and petals.

ertilization.—In order that an ovule may develop into a suitable pollen grain must be deposited upon the The transference of the pollen from the stamens to is termed **pollination.** When the stigma receives the stamens of the same flower, the latter is said **linated**; **cross-pollination** takes place when es the pollen from another flower.

wind are the chief agents for carrying ower to another. When the stigma is receive pollen, it is usually sticky, or tigma the pollen grain germinates which grows downwards into the

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Adventitious buds.—

cavity of the ovary. Here it comes into contact with the ovule, to which a portion of its contents is transferred. This fusion of the contents of the pollen grain and ovule is termed **fertilization.**

A flower is said to be **self-fertilized**, if it is fertilized with pollen from the stamens of the same flower; in other words, when fertilization follows as a result of self-pollination. When the fertilizing pollen is from another flower, the flower is said to be **cross-fertilized.**

It is important to distinguish clearly between pollination and fertilization. Pollination is the placing of the pollen on the stigma. Fertilization is the action of the pollen upon the ovule, and takes place within the ovary. After fertilization the ovule grows into a seed. Unless the ovule is fertilized it will die.

The essential parts of the flower.—The purpose of the flower is to produce seed, and for this purpose we have seen that only the stamens and pistil are absolutely necessary. These two parts are termed the **essential parts** of the flower. The calyx and corolla are only indirectly concerned in seed production. In many flowers one or both of these parts is missing; but all flowers possess either stamens or pistil.

The fruit.—Fertilization produces changes not only in the ovule, but also in other parts of the flower. The petals and stamens, and usually the sepals, fall off; the styles and stigmas wither, and the ovary grows to make room for the increasing size of the seed. The ripened ovary and whatever parts remain attached to it, form what is botanically described as the **fruit.** A pea pod is a ripened ovary, and therefore is a fruit.

In the strawberry not only do the ovaries increase in size after fertilization, but the receptacle swells and becomes succulent; so that the fruit consists mainly of an enlarged receptacle: what are commonly called the seeds are in reality ripened ovaries.

Anything that interferes with pollination may result in serious damage to crops that are grown for the sake of their fruit, or seed. The danger of loss owing to fertilization not being effected is greatest in the case of flowers that must be cross-pollinated before fertilization can take place.

Non-fertilization and its effects on the crop.—With the exception of a few plants, not of agricultural importance, unless the ovule is fertilized, fruit will not be formed; or, if it is formed, it will not mature.

It is also of importance in many cases that the fertilizing pollen should be from another plant, that is, the flower should be cross-fertilized. It has been proved that for many plants cross-fertilization has decided advantages over self-fertilization. The yield of seed is often increased, and the seed when sown is generally more vigorous and productive. Darwin found that cabbages from crossed seed were more than twice as heavy as those grown from self-fertilized seed. In some cases larger fruit is formed after cross-fertilization.

Some flowers will not form seed unless insects have access to them. Darwin covered up one hundred heads of red clover with a net to prevent the visits of insects to the flowers. These heads produced no seeds; while a hundred uncovered heads growing by the side of those that were covered produced 2700 seeds.

Wheat, barley, oats, peas, and beans are usually self-fertilized, and are not dependent on the visits of insects for pollination.

Of the common farm crops, the fruit crop is most likely to suffer when cross-pollination is prevented. Many varieties of apple, pear, plum, and cherry are not fertile either with their own pollen or with that from another tree of the same variety. These are said to be **self-sterile**. Such varieties will not produce fruit unless they receive pollen from a tree of a different variety.

Why apple flowers sometimes fail to set fruit.—The dependence of seed and fruit formation upon fertilization is well illustrated by the case of the apple, the flower of which has been described (Fig. 14). After fertilization, the blossom is said to "set" fruit; the receptacle enlarges and becomes the fleshy portion of the fruit (Fig. 16). The core of the apple is the ripened ovary.

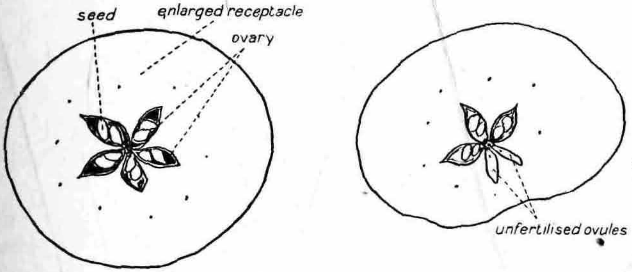

Fig. 16.—Section across apples. In the one-sided apple, the ovules in two of the divisions of the ovary have not been fertilized: consequently, the adjoining part of the receptacle has not developed properly.

Many varieties of apple are self-sterile. They can only be fertilized with pollen from another variety. If there are no suitable trees in the vicinity, or no means of conveying the pollen, the trees, although bearing abundance of blossom, fail to produce fruit. The pollen is chiefly carried by bees.

In an experiment recently described, one branch of a tree was covered with muslin before the flowers opened. This prevented any large insects, such as bees, gaining access to the flowers. "In each case the covered branch bore no fruit, while the remainder of the branches carried a good crop."

It may happen that one or more of the five stigmas present in the apple flower receives no suitable pollen. Seeds will not be formed in the corresponding divisions of the ovary, and that part of the receptacle adjoining will make less growth. The result is a one-sided apple (Fig. 16).

Among the chief causes preventing fertilization are:

1. Injury to the pollen or stigma by frost, rain, or hail.
2. Dull, damp weather, such as prevents the pollen being conveyed by wind or interferes with the working of insects.
3. Absence of pollen-carrying insects.
4. Absence of suitable pollen-bearing flowers.

Plant breeding.—The act of pollination may be artificially performed by the plant breeder when he wishes to secure a cross between two plants. Briefly, the method is as follows: the anthers of the parent flower which is to bear the seeds are carefully removed. This process is termed **emasculation**. The emasculated flower is then covered up with a bag, so as to prevent pollen from other flowers being conveyed to the stigma. When the stigma is receptive, some of the pollen from the ripe anthers of the other parent flower is collected and transferred to the receptive stigma. The flower is again covered up for a few days until the danger of fertilization by other pollen is past.

Regenerated seed.—Wheat, barley, and oats are practically always self-fertilized: in the ordinary course they do not secure the benefits that generally follow cross-fertilization. Sometimes, in the case of these plants, cross-pollination is effected by hand with pollen from another plant of the same variety. For example, pollen from a flower of Squarehead's Master is placed on the stigma of an emasculated flower of another plant of the same wheat. The flower becomes cross-fertilized, and the resulting seed gives rise to more vigorous and productive plants than seed from self-fertilized flowers. In this way the stock is said to be **regenerated**, and the seed from these cross-bred plants is sold by seedsmen as regenerated seed.

New varieties.—More often, two distinct varieties are artificially crossed with the object of combining in the offspring certain desirable features of both parents, and so new and better varieties are produced. Burgoyne's Fife wheat,

Standwell barley, and Waverley oats are examples of cereals produced in this way. Burgoyne's Fife wheat is a cross between Essex Rough Chaff and Red Fife. The latter is what is known as a **strong** wheat, and is worth more to the

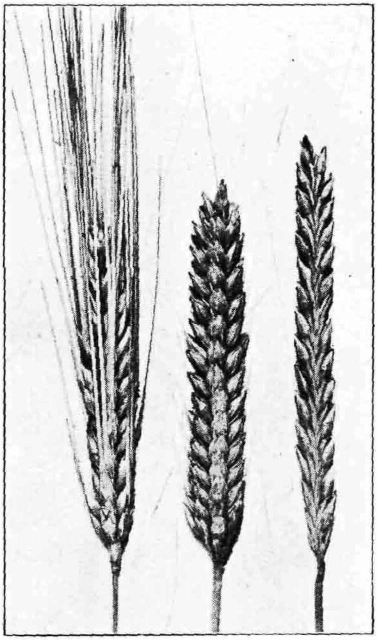

FIG. 17.—The new breed of barley shown in the centre was produced by crossing a six-rowed bearded variety with a two-rowed beardless barley. The parent forms are shown on each side.

miller than a **weak** wheat; but the yield is small and the straw inferior. Essex Rough Chaff is a weak wheat, but grows a good crop of both grain and straw. Burgoyne's Fife, the result of the cross, is a strong wheat that yields well, and so combines the good qualities of both its parents.

Fig. 17 is a photograph of a new breed of barley produced

by crossing. The parent form, shown on the left, has ears with long awns (bearded) and six rows of grains. It is a very productive variety, but the grain is of poor quality. The other parent, shown on the right, is a two-rowed beardless barley of fine malting quality. The progeny, which is shown in the centre, combines the quality and the beardless

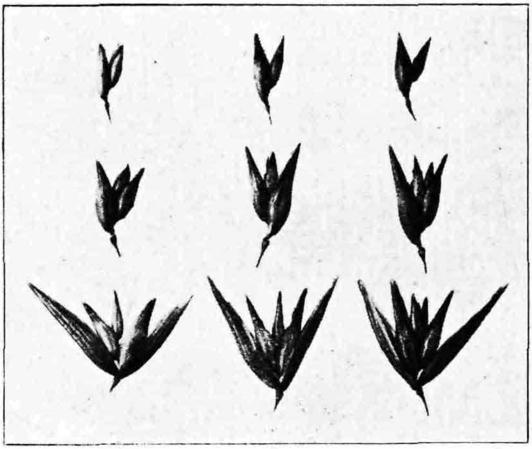

FIG. 18.—Spikelets of oats showing increase in size due to scientific breeding. New breeds at base; older varieties above.

character of one parent with the productive capacity of the other.

During recent years the crossing of oats has resulted in the production of many improved varieties. In Fig. 18 the three spikelets in the top row show the size of the grain of the three principal varieties cultivated thirty years ago; the two lower rows show the increase in size and number in each spikelet that has been developed by an extended course of scientific breeding.

Natural crosses.—A distinctly new plant, differing in some way from any other variety, may arise as the result of

a natural or chance cross between two varieties. If it is an improvement on older sorts, the plant breeder will endeavour to propagate it. The Hopetoun oat, for example, originated from a single plant, due probably to natural crossing, which was found in a field of oats.

Bud-varieties.—Sometimes a bud will develop into a shoot quite unlike the other shoots on the same plant. Such a shoot is known as a **bud-variety**. Perhaps it differs from the other branches in the colour of its flowers, the shape of its leaves, or the size and quality of its fruit. A bud-variety can rarely be propagated by seeds, but it may generally be multiplied by cuttings, by budding, grafting, or similar methods, and so become the parent or original plant of a new variety.

Bud-varieties are rare among farm crops, but not uncommon among garden plants. Many varieties of fruit trees, some potatoes, and possibly a few varieties of corn, have originated in this way.

New plants or parts of plants appearing spontaneously and without any apparent reason are termed **sports.** Gardeners generally use the term with reference to bud-varieties only.

EXERCISES.

PRACTICAL.

1. Cut across any one-sided apples you can get. Note if there are seeds in that division of the ovary nearest the badly developed side.

2. Examine a flower of strawberry. There is a large number of ovaries. Can you suggest any reason why strawberries should sometimes be one-sided?

3. Before the flowers open, cover some apple blossoms with muslin in such a way that bees cannot gain access. Remove the muslin about a week after the flowers have opened. See if fruits are set equally well in covered and uncovered blossoms. Test in the same way different varieties of apple; also pear, plum, and bush fruits.

4. Stand in a field of barley, and, without moving from one place, pull ten of the largest and ten of the smallest ears you can reach. Determine the average number of grains in (1) the ten smallest ears; (2) the ten largest ears; (3) the largest single ear; (4) the smallest single ear.

How many grains are there in the largest ear you can find in the field?

WRITTEN.

1. A farmer had a single cherry tree, which generally produced an abundance of blossom, but very little fruit. Can you suggest any reason for this and how the defect might possibly be remedied?

2. What do you understand by regenerated wheat?

3. What is meant by a bud-variety?

4. What is meant by the terms pollination, self-fertilization, cross-fertilization, and self-sterility?

5. Why is it important to the farmer that certain plants should be fertilized? Mention two causes that might prevent fertilization.

6. The introduction of hive bees into a certain district was followed by much better fruit crops. Why?

7. Draw a sketch showing what is seen on cutting an apple down the middle. Explain the nature of each part.

CHAPTER V.

DURATION OF PLANTS. VEGETATIVE REPRODUCTION.

PRACTICAL WORK.

1. Dig up a "root" of stinging nettle, and observe: (1) the horizontal underground shoots with distinct, thickened nodes, and adventitious roots, (2) the upright growing shoots bearing green leaves, (3) the remains of shoots of former years or the marks on the underground shoots indicating where they were attached, (4) buds or young shoots springing from the nodes underground. Determine which of these parts are present in charlock or groundsel.

2. Examine the underground parts of couch grass. Observe the thickened nodes and scale-like leaves; notice that the latter have buds in their axils.

3. Dig about 9 inches deep around three or four shoots of creeping thistle that are standing close together, and raise the sod with the thistles intact. Carefully knock off the soil, and determine whether the thistles are distinct individual plants, or are shoots from the creeping underground portion of one plant.

4. Examine creeping crowfoot. Observe the creeping stems with shoots and adventitious roots at the nodes. What will be the result of cutting across the internodes?

5. Put young shoots of willow in water and note the production of adventitious roots.

Annuals.—Fig. 19 is a drawing of charlock, known also as wild mustard, yellow weed, and preshaugh, and one of the most troublesome weeds of cornfields. The seed from which the charlock grew germinated in May. In July, when the drawing was made, the plant was in flower. After the seed has ripened, the charlock will die. No living part of the plant will be left in the ground to give trouble again. If charlock plants appear the following season they must have grown from seed. Plants such as charlock, which grow from seed, ripen seed, and die in one growing season are termed **annuals**. Other examples of common annuals are wheat, bean, poppy, and groundsel.

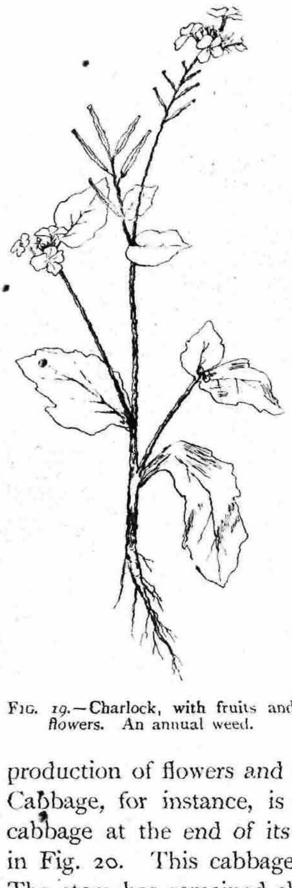

FIG. 19.—Charlock, with fruits and flowers. An annual weed.

Biennials.—Plants which complete their life-history in two growing seasons are termed **biennials**. They grow from seed, and during the first year store up nourishment in the root, stem, or leaves. The following season this store of nourishment is used up in the production of flowers and seeds, after which the plant dies. Cabbage, for instance, is a biennial. A photograph of a cabbage at the end of its first season is shown to the left in Fig. 20. This cabbage grew from seed sown in April. The stem has remained short, hence its leaves are crowded together, forming a head. The material manufactured in

the outer green leaves has been stored in the inner leaves of the head for use in the following year.

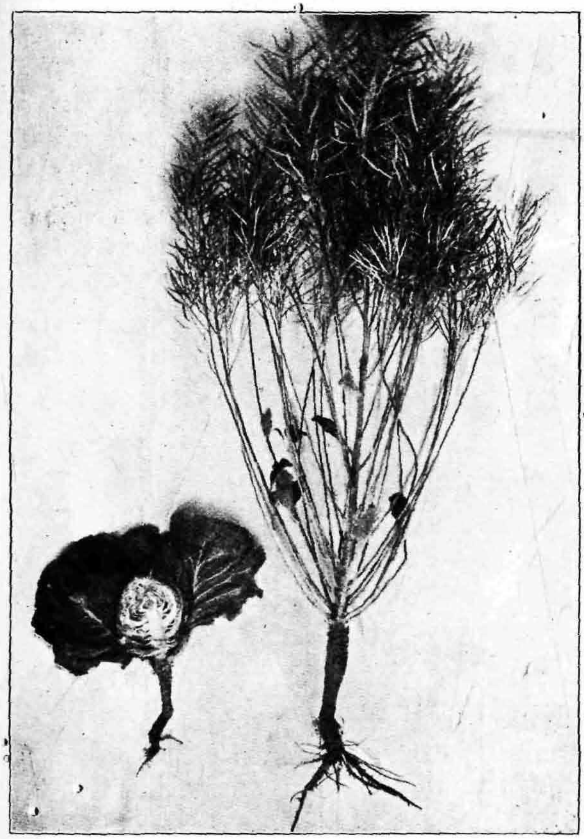

FIG. 20.—Cabbage at end of first and second seasons. Food is stored in the leaves during the first season; in the second, seed is produced, and the plant dies.

The other photograph shown in Fig. 20 is that of a cabbage at the end of its second season. The previous

autumn and early spring it was in the same condition as the plant shown on the left. During the summer its stem has lengthened, buds in the axils of the leaves have developed into branches, and on the ends of the stem and its branches, flowers have been borne. After ripening seed, the plant is exhausted and dies. New cabbage plants must be grown from seed.

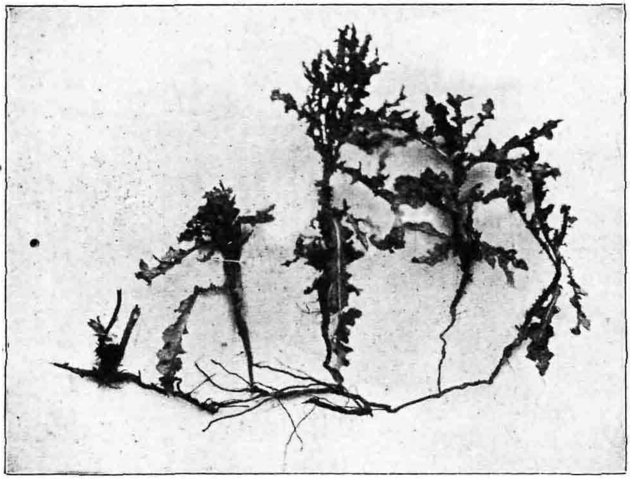

FIG. 21.—Creeping thistle. The shoots die down in winter; in the spring, new shoots arise from the perennial underground parts. Remains of old shoot seen on the left.

Other common biennials are turnip, mangel, carrot, and marsh thistle. Plants which are usually biennials may produce seed the first year, and so become annuals. This is common in mangels, for example. They are then said to "bolt" or "run to seed." If a large number "bolt," it is a serious loss to the farmer, because they do not then lay up a store of food in the roots.

Perennials.—Plants which live more than two years are

termed **perennials**. In trees and shrubs the shoot becomes woody. They are known as **woody perennials**. In **herbaceous perennials** the shoot above ground is soft and dies down each season. The following year new shoots are produced from the underground parts. The creeping thistle (Fig. 21) is an herbaceous perennial. In winter the stems die down, but the roots give rise to new shoots, which appear in the following spring. Other examples of herbaceous perennials are stinging nettle, couch, colt's-foot, dock, potato, and most grasses.

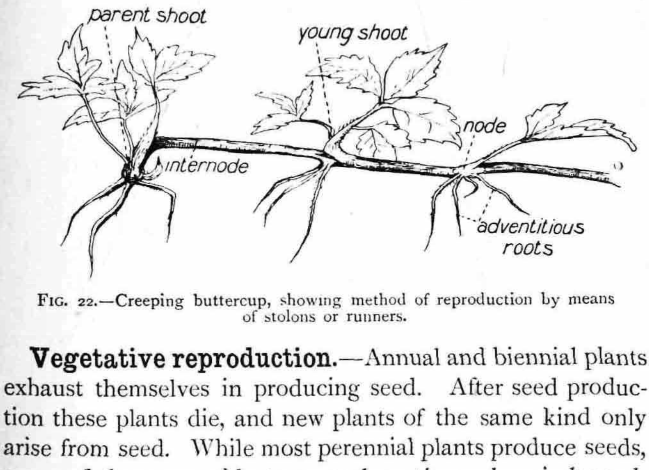

FIG. 22.—Creeping buttercup, showing method of reproduction by means of stolons or runners.

Vegetative reproduction.—Annual and biennial plants exhaust themselves in producing seed. After seed production these plants die, and new plants of the same kind only arise from seed. While most perennial plants produce seeds, many of them are able to reproduce themselves independently of seeds. Take, for instance, creeping buttercup, or crowfoot (Fig. 22), which is a common weed of cornfields. The weed is usually first introduced into a field as seed. When the plant becomes established, some of the shoots arising in the axils of the lower leaves creep along the surface of the ground. The buds at the nodes of the creeping stems grow into upright shoots, and are fixed in the ground by adventitious roots. By the death of the intervening

portions, these shoots are separated from the parent shoot and form independent plants.

Any individual plant of crowfoot may have grown either from a seed or from a bud which has become detached from its parent. A shoot such as that of creeping crowfoot, which creeps along the surface, producing buds and adventitious roots at the nodes, is termed a **stolon** or runner. Strawberries and many grasses are propagated by stolons.

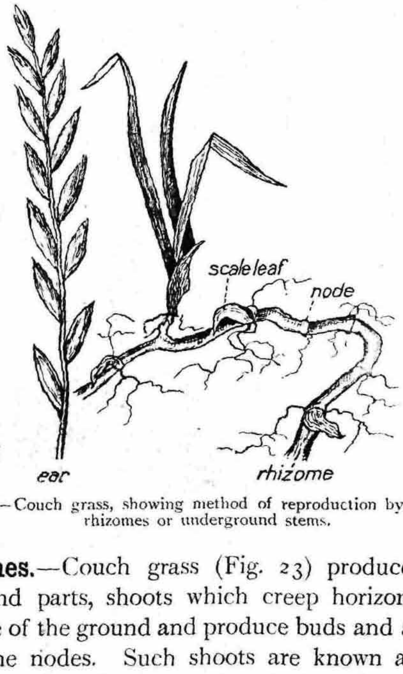

FIG. 23.—Couch grass, showing method of reproduction by means of rhizomes or underground stems.

Rhizomes.—Couch grass (Fig. 23) produces, from its underground parts, shoots which creep horizontally *under* the surface of the ground and produce buds and adventitious roots at the nodes. Such shoots are known as **rhizomes.** They look rather like roots, but bear reduced, scale-like leaves: roots never bear leaves. The rhizomes form what the farmer calls *couch*, *twitch*, *scutch*, *whickens*, or *stroyle*. The buds at the nodes develop into shoots bearing flowers

and green leaves. These shoots become separated from the parent shoot by the decay or by the cutting of the connecting rhizome, and thus form independent plants. Any piece of rhizome on which there is a node may give rise to a new couch plant. Other examples of self-propagation by means of rhizomes are seen in colt's-foot, nettle, and potato.

Tubers.—In the potato, the ends of the rhizomes become swollen and form the potato tubers. The "eyes" are buds borne in the axils of greatly reduced leaves. That the potato is a shoot and not a root is further shown by the fact that when exposed to the light it becomes green, just as in the case of an ordinary shoot. The eyes do not, as a rule, develop until the next season. When the tubers are planted in the following spring, one or more of the eyes grow into upright green shoots, and produce, in the axils of their lower leaves, new tuber-bearing rhizomes. If these rhizomes become exposed to the light, they develop into ordinary shoots bearing green leaves. Only in raising new varieties are potatoes grown from seed. Many varieties do not produce seed under ordinary methods of cultivation.

Bulbs.—A few plants reproduce by means of **bulbs**. A bulb consists of a short stem with thick fleshy leaves in the centre and protecting scale leaves on the outside. It is a large bud in which reserve material is stored in the inner leaves. Towards the end of the year, the tulip and narcissus, for example, form one or more bulbs in the leaf axils of the old bulb. These young bulbs give rise to new plants the following season. The onion does not, as a rule, reproduce itself by bulbs. It is a biennial, storing up reserve material in its bulb the first season, and dying after seed production the following year. Occasionally, however, the onion forms one or more bulbs during its second season, and thus provides for another year's growth. It is then a perennial.

Corms.—The crocus, and a few other plants, reproduce themselves by means of **corms**. This is a form of shoot

somewhat similar to a bulb in appearance. It consists of a short, thick stem, with a few protective scale leaves on the outside and one or more buds at the top. The reserve material is stored in the stem, not in the leaves, as in the bulb. After flowering, the old corm shrivels up, but new corms are formed by the deposition of reserve material in the short stem of the new shoot.

The multiplication of plants, by means of parts other than seeds, which become separated from the parent and form independent plants, is termed *vegetative reproduction*. In the cases we have so far considered this separation takes place naturally; but parts are often artificially separated from plants and used as a means of propagation.

Take the apple, for example. All the trees of any established variety have been derived by artificial vegetative reproduction from one original tree, or perhaps from a single branch of a tree. The original tree may have grown from seed, but the variety is never reproduced in this way.

Cuttings.—Potatoes are not usually planted whole, but are cut in several portions, each portion having one or more "eyes." This is an example of multiplication by **cuttings**: portions of a plant removed and planted. Usually the cutting is part of a shoot, and when planted in suitable soil it produces adventitious roots at the nodes, and thus becomes an independent plant. Geraniums, gooseberries, and currants are examples of plants commonly propagated by cuttings.

Layering.—With cuttings, especially cuttings of herbaceous plants, there is a danger that the reserve material may be used up, or the cutting wilt owing to transpiration, before the roots have developed. This difficulty is overcome by the process of **layering**. In layering, a shoot is partly cut through, then bent over and pegged down in moist soil. Near the cut portion of the layer, adventitious roots arise. The layer is only severed from the parent plant after a good root system has been developed.

Budding and grafting.—Apple, pear, rose, and many other trees are usually propagated by **buds**, or by **grafts**. In budding (Fig. 24), a bud is removed from one tree and inserted into another tree, which is known as the **stock**. The bud becomes united with the stock, and later develops into a branch. The operation is usually done in June, July, or August. A shield-shaped piece of bark and a little of the

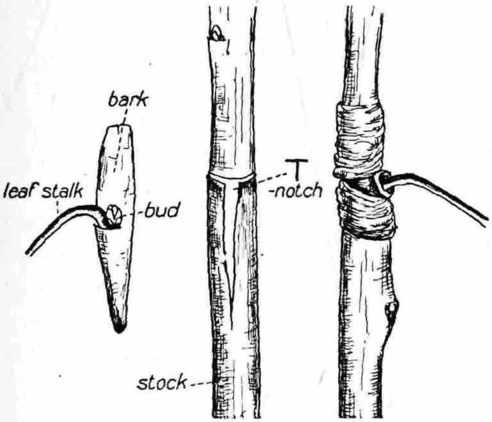

FIG. 24.—Showing a common method of budding.

underlying wood is removed with the bud. The wood is carefully removed without injuring the interior of the bud. Upon the stock a T-shape cut is made, and the bark gently raised. Into this incision the bud is inserted and secured with bast, or wool. If the operation is successful, the bud and stock unite in a few weeks, and the binding material may then be removed.

Grafting (Fig. 25) is very similar to budding, except that a shoot with several buds is used instead of a single bud. From the tree which it is desired to propagate, one year old

shoots are removed in November, and kept during winter with their cut ends in soil. The following March one or more of these shoots, or grafts, are fastened to the cut end of the stock in such a way that the actively growing layers in each are in close contact. If the stock and graft unite, the buds on the latter develop into branches during the current season.

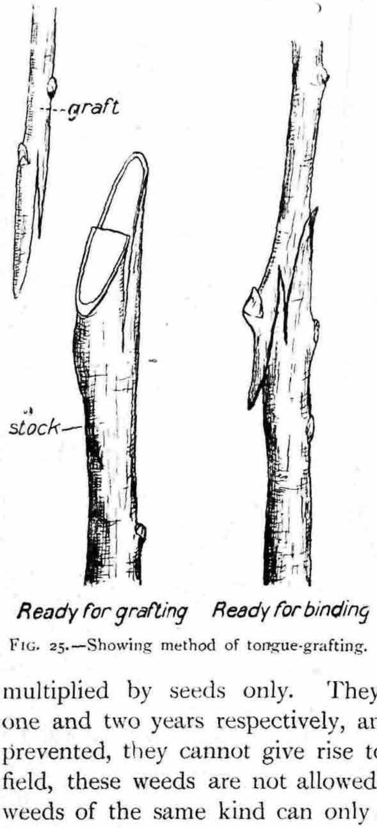

FIG. 25.—Showing method of tongue-grafting.

Destruction of weeds.—The farmer has to wage constant war against weeds. What we have learned regarding the length of life and means of propagation of plants will indicate how this can best be done. Annual and biennial weeds are multiplied by seeds only. They themselves die within one and two years respectively, and if seed production be prevented, they cannot give rise to new plants. If in any field, these weeds are not allowed to bear seed, then new weeds of the same kind can only appear if their seeds are introduced, or from seeds that have remained dormant. Take charlock, for example; when growing among root crops it is generally destroyed in the seedling stage by the operations of hand and horse hoeing. In corn it is more difficult to get rid of. Many plants are destroyed by harrowing before

the corn is sown, and also by harrowing before the corn gets too high. Charlock plants may be pulled up if not too numerous; or they may be killed by spraying with a solution of copper sulphate. If the latter operation is carried out under proper conditions, the plant is killed. Although by these methods seeding is prevented, new crops of charlock may arise from seed which has been brought to the surface after being buried perhaps for many years.

Perennials are the most difficult weeds to deal with. It is important to prevent seeding, but they cannot be eradicated or kept from spreading by this means alone. Many perennial weeds are spread by means of rhizomes, or by stolons, and from comparatively few plants of such weeds a field may become overrun with weeds without any seeds being produced.

When cut near the surface, most perennial weeds develop new shoots on their underground parts. Cutting prevents seeding for the time, but results in a number of shoots being produced in place of the one removed. If, however, the succession of new shoots are cut as they appear, the plant will ultimately be exhausted and die. The reason for this is explained in Chapter VI. To make sure of destroying weeds of this class, the underground parts must be removed from the ground, or dragged to the surface and killed by drying. Breaking up the underground parts only spreads the weed, for the separate portions form cuttings. This happens, for instance, when couch rhizomes are cut in ploughing. It is better to drag or fork out the rhizomes, and so collect them without their being broken.

EXERCISES.

PRACTICAL.

1. Examine creeping stems of white clover, and determine in what way it is reproduced apart from seed.

2. In summer, cut up into several pieces a root of dock and a root of mangel or carrot, and plant in soil. After about three weeks dig the pieces up and compare them.

3. Dig up a rhizome of couch grass, cut into similar sized lengths, so that some include a node and others consist only of the internode portions. Plant in separate pots of moist soil, and observe which produces new shoots.

4. In summer, remove the earth from a potato and examine the "eyes" on the tubers with a magnifying glass. Note that they are produced in the axils of very small leaves. Leave a tuber exposed to the light, and note that it turns green.

5. Get a gardener to show you the operation of budding in July and of grafting in March.

6. Make a 4% solution of copper sulphate (*i.e.* 4 grams to 100 c.c. of water), and with this paint the leaves of charlock, corn, turnip, mangel, thistle, and other plants. Compare the effect in each case.

WRITTEN.

1. Why do you consider a tuber a stem and not a root?

2. Describe fully how the following plants reproduce themselves: couch grass, mangel, creeping crowfoot, and charlock.

3. Describe the operation of budding.

4. Explain why creeping thistle is generally found in patches of several together, whereas marsh thistle (a biennial) is usually found singly.

5. What is a cutting? How does it differ from a layer?

6. Describe the life-history of some annual and of some biennial plant.

7. Explain why it is usually more difficult to exterminate perennial, than annual and biennial weeds.

CHAPTER VI.

COMPOSITION OF PLANTS. CARBON ASSIMILATION.

PRACTICAL WORK.

1. Weigh out about 10 grams of freshly-cut grass. Set aside for two or three days in a warm place until the grass is "hay-dry." Weigh again; note the loss in weight. Place the hay in a water oven, or near a fire, for a few hours (taking care in the latter case that the heat is not sufficient to char the hay). Cool and weigh again, and note the further loss in weight.

Spread the dry hay on a plate and apply a light. After the flame has died down, brush the charred material into a weighed crucible, taking care that none of the charcoal is lost. Ignite, at first very gently, and then more strongly, until all the black specks disappear and a greyish-white ash is left. Weigh again; the increase in weight gives the amount of ash.

Calculate, and state as a percentage (*a*) the loss of water when grass is made into hay; (*b*) the amount of water in hay; (*c*) the amount of dry matter in grass and hay respectively; and (*d*) the amount of ash in grass.

2. Take some bean meal (which may be made by rubbing a dry bean on a file); mix it well with a little soda-lime and heat in a test-tube. Ammonia is given off and may be recognized (1) by its smell, and (2) by its action on moistened red litmus paper.

Test in the same way some white of egg and some powdered cotton cake.

3. Burn a handful of hay on a plate and hold a glass jar above it so as to collect the gases given off. After a few seconds close the mouth of the jar with a saucer. Raise the saucer slightly and pour a little clear lime-water into the jar. Replace the saucer and shake well. The lime-water becomes turbid. This chalky appearance of the lime-water indicates that carbon dioxide has been given off by the burning hay.

4. By the methods described on page 8, test a potato tuber, or dock root for starch, and flax, or turnip seeds for oil.

Note the sweet taste due to the presence of sugar in roots of swede or mangel.

5. On a bright afternoon pluck leaves of turnip, mangel, and sycamore, and dip them into boiling water for a minute or two. Soak the treated leaves in methylated spirit until the green colouring matter has been dissolved out. Immerse the bleached leaves in a solution of iodine. The colouring shows the presence of starch in the leaves.

6. On the upper side of a leaf of turnip, mangel, or sycamore, place one half of a split cork. Hold the other half exactly underneath its fellow, and fasten with a pin which passes through the two pieces of cork and the leaf between. Leave for a day or two, and after a few hours further exposure in a bright light, detach the leaf from the plant and go through the process of testing for starch as explained in Expt. 5. Compare the results obtained in each experiment, and find what influence darkness has had on the formation of starch in the leaf.

What the plant is made of.—When grass is cut and allowed to lie in the sun and wind for a few days, it is changed into hay. In this process water is evaporated. A crop of grass weighing 6 tons per acre will yield about 2 tons of hay, so that 4 tons of water have been lost in drying. It is evident, therefore, that living grass is made up chiefly of water. But all the water is not got rid of in the process of hay-making. The apparently dry hay still

contains some water, which can only be got rid of by heating to a temperature much higher than that of the air. If the 2 tons of hay referred to above were treated in this way, they would lose a further half ton of water. Hence in 6 tons of grass we would find only about 1½ tons of perfectly dry substance.

If a match be applied to the dry substance, the latter will burn, and when the flame has died down there will be left a charred mass. What remains is chiefly black charcoal. On heating much more strongly, the charcoal disappears, and there is left a little greyish-white ash, which will not burn away however long the heating is continued. If the 1½ tons of perfectly dry substance obtained from the 6 tons of grass are burnt, about 2 cwts. of ash remain.

From the above figures we obtain by a simple calculation the following results: growing grass contains 75 per cent. of water and 25 per cent. of dry material. Of the dry matter 23 per cent. is combustible; the remaining 2 per cent. consists of ash.

Water in plants. At some stage of their growth all plants contain more than half their weight of water. Grass, as we have seen, may contain about 75 per cent. In turnips and mangels there may be 85 to 90 per cent. of water, and even the ripe and apparently dry seeds from which these crops grew probably contained as much as 12 per cent. of water.

Elements present in plants.—The charring of the plant material during the first stages of burning is evidence of the presence of the element **carbon** in the plant. We are familiar with this substance in the form of charcoal, which is got from partly burnt logs of wood. During combustion the carbon combines with the oxygen of the air, and carbon dioxide (carbonic acid gas) is produced. The presence of carbon dioxide may be shown by collecting and shaking up with lime-water the gases given off by the burning plant. The carbon dioxide unites with the lime-water to

form carbonate of lime, or chalk, and this gives the water a characteristic chalky appearance.

If a little of the dry material be mixed with soda-lime and heated, ammonia will be given off, and may be recognized by its smell. Ammonia is a compound of **nitrogen,** and its production in this way is proof of the presence of nitrogen in the substance treated.

By simple chemical tests the presence of other substances may be detected. The following elements are always found in the green plant: in the combustible part there is **carbon, hydrogen**, **oxygen**, and **nitrogen**; while in the ash there is found **potassium**, **calcium**, **magnesium**, **iron**, **phosphorus**, and **sulphur**. Besides these, several other elements are generally present in the plant. The ten elements named are known as the **essential constituents of plants**, because they are indispensable to plant life.

That the plant cannot live without all these substances may be shown by the method known as **water-culture.** Here plants are grown in jars of water; to one of these jars all the essential elements are added in suitable forms; while in the case of the other jars each element is omitted in its turn. Thus, one jar is supplied with all the elements except nitrogen, another receives no phosphorus, and so forth. It is not necessary to make any provision for the supply of carbon, as the plant will obtain this element from the carbon dioxide in the air. It is found that in all cases where one or more of these elements is omitted from the culture solution the plant will suffer.

Some important compounds in plants.—In the plant the essential elements do not exist by themselves, but are found grouped together to form more or less complex compounds. We have seen in Chapter I. that certain seeds contain large quantities of **starch**. This is a compound of carbon, hydrogen, and oxygen, and is one of the members of a large class of compounds termed **carbo-**

hydrates, in which the hydrogen and oxygen are present in the same proportion as they occur in water. Another carbohydrate common in plants is **sugar**, which is found abundantly in sugar-beet, mangel, and turnip; **cellulose**, of which the cell walls of plants are built, is a third example of a carbohydrate. Blotting paper and cotton-wool consist almost entirely of pure cellulose.

Oil is found in many seeds, such as linseed and mustard. Oil is also a compound of the three elements, carbon, hydrogen, and oxygen; but here the proportion of oxygen is lower than in carbohydrates.

A third important class of bodies is represented by the **albuminoids**. These contain carbon, hydrogen, and oxygen, together with sulphur and nitrogen. White of egg is an albuminoid. Among farm crops, clover, beans, peas, and vetches, especially their seeds, are richest in albuminoids.

Many other compounds are present in plants besides the carbohydrates, oils, and albuminoids, but in estimating the feeding value of plants it is these three compounds which the farmer must chiefly consider.

Sources of plant food.—The elements making up the bodies of plants are derived from the soil and the air. Green plants obtain their carbon from the air by means of their leaves; the remaining elements are taken up from the soil by the roots.

Carbon assimilation.—Usually more than half the dry matter of plants consists of carbon. We have seen that carbon dioxide is produced when plants are burnt. The same gas is formed within our bodies and is exhaled in breathing. The carbon dioxide produced in these and many other ways escapes into the atmosphere, and is found in the air to the extent of about three parts per 10,000.

In the leaves of plants there are numerous minute openings called **stomata** (Fig. 26), through which the air with its small proportion of carbon dioxide passes. Under the

influence of sunlight, and in those parts of the plant which contain the green colouring matter known as **chlorophyll**, some of the carbon dioxide is split up: oxygen is set free and the carbon retained. In the cells of the leaf this carbon combines with water to form a carbohydrate. This process is termed **assimilation**. Briefly, it may be represented thus:

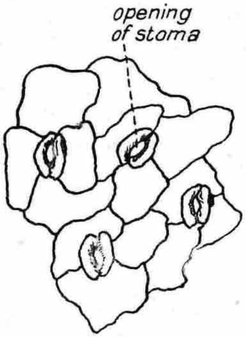

FIG. 26.—Surface view of part of underside of cabbage leaf, showing four stomata. (×300.)

carbon dioxide + *water*
(from the air) (in the leaf)

= *a carbohydrate* + *oxygen*
(retained by plant) (returned to air)

The first visible carbohydrate to be formed is starch. The fact that starch is present in the leaf, and that oxygen is being given off, is evidence of assimilation.

If a stone water trough be examined on a bright day, bubbles of gas may be seen adhering to the green algæ and moss at the bottom of the water. This gas is chiefly oxygen, and has been set free by the green plants from the carbon dioxide dissolved in the water. By noting the rate of evolution of oxygen from water-plants (*e.g.* cress) placed under water, the influence of light and temperature upon assimilation can be studied.

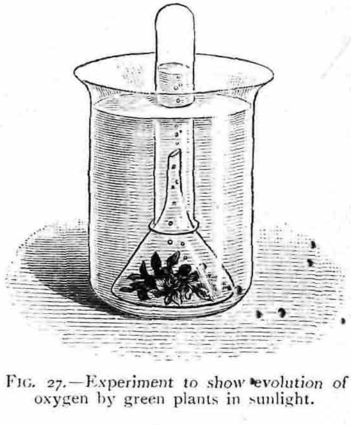

FIG. 27.—Experiment to show evolution of oxygen by green plants in sunlight.

The presence of starch in a leaf may be detected as follows. The leaf is first killed by being dipped into boiling water for a minute or two, and is then placed in methylated spirit so as to dissolve out the chlorophyll, which would otherwise disguise colour changes in the leaf. The bleached leaf is now treated with iodine solution, and where starch is present the leaf turns dark-blue, or black.

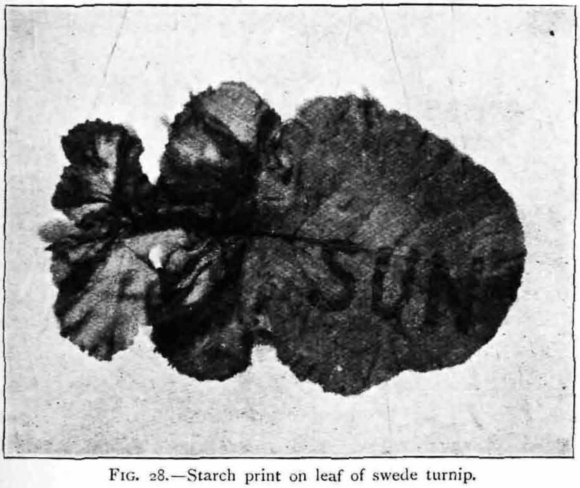

FIG. 28.—Starch print on leaf of swede turnip.

The starch produced in the leaf during assimilation is not retained there permanently, but is transferred to other parts of the plant. During daylight, starch is removed less rapidly than it is formed, so that it accumulates in the leaf; in the dark, when no fresh starch is being made, the leaf becomes depleted of its store of starch.

Fig. 28 is a photograph of a swede leaf to which has been pinned a piece of black paper with the word "sun" cut in it. Light could only fall on the leaf through the cut-out part of the paper. The paper was left on the leaf for

two days, and then, after several hours' further exposure in bright sunlight, the leaf was detached from the plant and tested for starch in the way described above. That part of the leaf which was exposed to the light was turned black. This shows that it is only where light has access to the leaf that starch is formed. In the covered parts of the leaf the starch originally present has disappeared during the course of the experiment. The energy of the sun has been utilized by the leaf for the work of decomposing carbon dioxide and water to produce starch. The word printed on the leaf is literally a sun-print.

Carbon assimilation only takes place in the green parts of plants and in the presence of sunlight. A certain temperature is also necessary, and of course there must be carbon dioxide present in the air surrounding the plant.

The carbohydrates found in the leaf form the basis from which the oils, albuminoids, and other compounds are built up.

Importance of leaf development.—The leaves are the chief assimilating organs of the plant. Adequate leaf development is therefore necessary for good yields of crops. It does not follow, however, that the leafiest crops will give the heaviest yield: big-topped potatoes, for example, often give disappointing returns, because the starch formed in the leaves has gone to produce leaf-bearing stems rather than large tubers.

Effect of destroying leaves.—The removal of the leaves as they appear, and the consequent stoppage of carbon assimilation, will weaken and ultimately kill all plants. This is why many perennial weeds, such as creeping thistle (Fig. 21), may be destroyed by cutting at frequent intervals. If thistles are cut in June, some of the food stored in the underground parts will be used to produce new shoots. These are cut down again in July or August. Since the time of the previous cutting the amount

of carbohydrate elaborated by the new leaves will not have been sufficient to compensate for the loss of stored-up material that has been used in the formation of the new shoots. This results in a weakened plant. A third cutting in September will probably exhaust, and so kill, the thistles. In some cases, however, it may be necessary to repeat the cuttings the following season.

To destroy weeds in this way the cutting must be done at short intervals, in order that the plant may lose more by the removal of its organs of assimilation than it gains between each cutting by the process of assimilation. When long intervals elapse between the cuttings, the plant may grow more leaves than it had before, and the weed become more vigorous than ever. The ragwort (Fig. 10) is an example of this.

Necessity of light.—We have seen that light is necessary for carbon assimilation, which, as a rule, takes place most actively in bright sunlight. Plants can grow in the dark: germinating seeds and sprouting potatoes do so when completely buried in the soil. But they can only grow at the expense of reserve material. As the latter is also diminished by respiration, the plant soon dies, unless its leaves come to the light before all the stored food is used up.

What happens when plants are grown in darkness is seen in the case of early rhubarb. The plants are forced, either by removing the roots to warm, dark houses, or by covering up plants in the open with inverted barrels, boxes, etc., and surrounding these with manure. As the leaves are in darkness no carbon assimilation can take place, and the dry matter required for leaf growth can only be obtained from the supply stored in the roots. Grown in this way for a season, the roots are so impoverished that they cannot be grown in the same way the following year; but are usually thrown away. The plants would need to be grown in the

light, and without having their leaves removed, for several seasons in order to regain the dry matter lost by one year's growth in darkness.

Weeds may be destroyed by covering with tarred paper or similar material which will exclude light from the leaves.

Grass and clover seeds are usually sown with a corn crop, and occupy the ground after harvest. On highly manured land, especially in a wet season, the stems of corn are liable to break, and the corn is said to become **laid** or **lodged.** The result is that the grass and clover growing among the corn are deprived of light, carbon assimilation is hindered and the young plants often die before the cutting of the corn again exposes them to the light. Sometimes the injury is such, that the field instead of having a good cover or "take" of grass and clover plants after harvest has to be ploughed up and other crops sown. In other cases the damage only occurs in patches. Where, however, the plants have merely been checked, and not killed outright, they recover after harvest.

Weeds injure crops, not only by robbing them of moisture and plant food, but also by shading the crop from the light. The injury is most serious, when, from any cause such as bad seed or poverty of soil, the crop is backward and the weeds get ahead. On the other hand a heavy crop so shades the weeds that they are weakened or killed.

For example, when potatoes have strong tops, closing across the drills and growing until late in the season, the growth of weeds is checked and the land is usually clean when the potatoes are raised. With small-topped potatoes, or where disease causes the tops to die down early, the drills in autumn are usually rank with weeds.

Fungi (*e.g.* mushrooms) and certain parasitic plants possess no chlorophyll, and so cannot obtain their carbon from the air, but must obtain it from ready formed organic substances: for instance, the fungus causing the potato disease feeds on the living plant, and the mushroom on dead plants.

EXERCISES.

PRACTICAL.

1. Cut down a patch of nettles, cover half the patch with a piece of black tarred paper pegged down on to the soil, or with an inverted box, so that the plants underneath are in darkness. Compare the growth of the covered weeds with that of the exposed weeds.

2. On a bright afternoon pluck a leaf of variegated geranium. Test the leaf for starch in the manner described on page 59. Note that starch is only present in those parts of the leaf which were originally green.

3. Place some young shoots of water-cress, elodea, or other water-plant in a large beaker of spring, or tap, water (Fig. 27). Insert an inverted filter funnel in the beaker so as to keep the plant wholly immersed. Expose the whole to bright sunlight, and note that bubbles of gas are given off from the shoots. Shade the beaker, and see if the bubbles continue to come off as fast as before.

The gas given off is chiefly oxygen. By placing a test-tube full of water over the stem of the funnel, the gas may be collected. Test the gas with a glowing chip.

4. Germinate two lots of mustard seed between a cylinder of blotting-paper and the side of a glass tumbler, as described on page 19. Keep both lots in the dark until the seed leaves appear. Bring one lot to the light, and make notes every three days of the appearance of each set.

5. During summer, in fields where grass seeds have been sown with the corn, compare the growth of the young grass and clover plants on patches where the corn is lodged with that of the plants among the standing corn. Also compare the growth of the grass and clover where the corn is thick and where it is thin.

WRITTEN.

1. State fully two different methods of eradicating weeds. Give examples. What is the theory underlying the practices you refer to?

2. Name the elements essential for plant growth. Mention two important classes of compounds found in plants, and give examples of plants which are rich in these compounds.

3. Explain in detail how you would determine the principal substances of which barley straw is composed.

4. What is carbon assimilation?

5. How would you show the difference in the production of starch by the white and green parts of a variegated maple or geranium leaf? What is the cause of this difference in the parts?

6. A wheat crop may weigh several tons per acre, though only two bushels of seed were put in. Whence does this large amount of matter come?

7. A cow requires about 24 lbs. of dry substance per day. If this is to be supplied in the form of (1) hay, (2) grass, (3) mangels, how much of each would be required?

8. When rhubarb plants are to be forced in darkness, it is usual, during the previous year, to allow the leaves to die down and not pull them as in the ordinary course. Explain fully the reason for this.

CHAPTER VII.

TRANSPIRATION AND RESPIRATION.

PRACTICAL WORK.

1. Let the stalk of a cabbage leaf dip into water coloured red with eosin or red ink. Keep the leaf in a warm room exposed to a good light. After one hour cut across the veins, and find how far the red colouring matter has passed into the leaf.

2. During bright weather fix a leaf of barley, or clover, or a small-leaved shoot like privet, into a wide test-tube by means of a plug of cotton-wool, as shown in Fig. 29. Examine the following day, and see if any water has collected in the tube.

3. Blow through a glass tube into lime-water: note that the liquid quickly turns chalky, owing to the fact that the air expelled in breathing contains a large amount of carbon dioxide.

4. Into a good sized bottle place a few sprouting potatoes, or creeping shoots of white clover, or about 100 germinating wheat seeds. Cork the bottle, making it air-tight, and keep in a warm, dark room. After two days remove the stopper, and gently pour the air from the bottle into a jar containing a little lime-water. Close the mouth of the jar, and shake well. The carbon dioxide given off by the plants turns the lime-water chalky. What does this suggest to you?

Transpiration.—When plants give off water vapour they are said to **transpire**. The process of transpiration goes on

almost continuously, and takes place chiefly through the stomata of the leaves (Fig. 26).

The fact that plants do transpire may be shown by slipping a test-tube over a slender growing shoot or narrow leaf, and packing the mouth of the tube with cotton-wool. The water vapour transpired by the leaf condenses inside the tube, and by the following day a considerable quantity of water will have collected (Fig. 29).

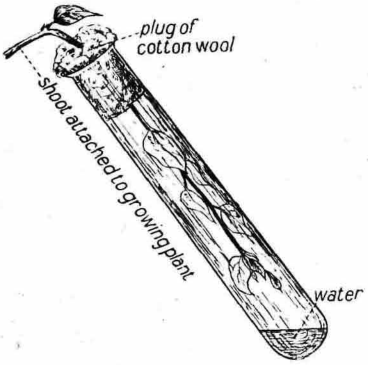

FIG. 29.—Experiment to show transpiration.

As water is removed by transpiration from the leaves, it is replaced by water containing food materials in solution, which is absorbed by the roots from the soil. Thus, a stream of water is almost constantly passing from the roots to the leaves, to be given off as invisible water vapour. The dissolved food material which the water contained when it was taken up by the roots is left behind in the plant.

Water required by crops.—Big crops can only be grown when there is an ample supply of water for transpiration. It is estimated that for every ton of dry matter produced in the plant, from 200 to 300 tons of water are given off. A heavy crop of turnips might transpire as much as 1000 tons of water per acre.

Owing to the removal of water from the soil by transpiration, land bearing a crop will be much drier than the same soil lying fallow. Weeds and hedgerow trees rob the soil of large quantities of water, and this is partly why they are so injurious to crops.

Transpiration is increased by bright light, dry air, wind, and warmth.

Effects of excessive transpiration.—The plant which cannot obtain sufficient water from the soil to replace that lost by transpiration gradually withers or **wilts**, and unless the balance between loss and gain is soon restored, it will ultimately die. If the plant is to live, either the roots must take up more water, or the leaves must transpire less.

Plants frequently die in hot weather because there is not sufficient water in the soil to meet the demands of transpiration. On the other hand, even with a sufficient supply of water in the soil, the roots may be unable to absorb it fast enough. This happens when the roots are injured in any way; as, for example, when they are attacked by insects, or torn in transplanting.

If young seedlings or plants recently transplanted are carefully protected from sun and wind until their roots have become well developed, transpiration will be so reduced that there is little danger of the plants wilting.

The farmer generally sows his grass seeds upon land that is also growing a corn crop. One of the advantages of this is that the corn protects the young grass plants against undue transpiration during their first summer. The corn is said to be a **nurse crop.**

Respiration.—We have learnt that in assimilation carbon dioxide is absorbed and oxygen given off. Exactly the opposite process also takes place in plants: oxygen is absorbed and carbon dioxide given off. This process is known as **respiration**, or breathing. That animals must breathe in order to live is well known; but that respiration is just as necessary for plants is not so generally recognized. The oxygen absorbed in respiration is essential for the processes of growth, and for the chemical changes necessary for the life of the plant.

Except in the case of some of the lower forms of plant life (*e.g.* certain bacteria), all plants obtain from the air the

oxygen required for respiration. The air contains about one-fifth of its volume of free oxygen.

Respiration and growth.—The carbon dioxide produced during respiration has been formed by the slow burning of the carbon in the plant. It is clear that respiration must result in a loss to the plant of dry matter. In this respect it is the converse of assimilation, which results in a gain of dry matter to the plant. As respiration is always taking place, day and night, in all parts of the living plant, a plant that is not assimilating carbon must lose in dry weight. This occurs, for instance, in germinating seeds before the seedlings reach the light, and in stored roots and tubers. A pit of potatoes in February will not contain as much dry matter as in the previous September when the potatoes were put in the pits. The tubers have been respiring all the winter, and, if they have also sprouted in the pit, the loss of dry matter due to respiration will be considerable.

Because more work is being done in our bodies, we respire much more rapidly during and after severe exertion than when at rest. For the same reason, respiration is most active in rapidly growing plants and in growing organs, and is reduced to a minimum in the case of plants such as bulbs, tubers, and seeds, which are in a resting condition.

That growing plants respire vigorously may be shown by placing sprouting potatoes, or germinating seeds, in a stoppered bottle which is kept in darkness. After a day or so the air inside the bottle will extinguish a lighted taper and turn lime-water chalky, proving that oxygen has been used up and carbon dioxide produced.

In the light, green leaves give off, through assimilation, more oxygen than is absorbed in respiration; but in darkness assimilation ceases, and it can be shown that respiration is taking place in the leaves just as in those parts that are not green.

Heat produced during respiration.—The burning of

carbon during respiration produces just as much heat as if the same amount of carbon had been burnt quickly in a fire, but the heat is given off so slowly that it is not usually noticed.

When, however, large amounts of respiring material are heaped together, the heat due to respiration may result in a marked increase in temperature. For instance, when "roots," such as potatoes or mangels, are put into large heaps in autumn and covered with soil to protect them from the frost, the roots get warm. This increase in temperature is due chiefly to respiration which is much more active during the first few weeks of storage than at a later period. The farmer, therefore, does not completely cover the heap, but leaves openings at the top, for a few weeks at least, to provide for the escape of the warm, moist air; if this were not done, the roots would spoil.

That heat is set free during respiration may be shown in the following way. Seeds are germinated in a thermos flask. This flask is used to prevent, so far as possible, the escape of heat from the respiring seeds. In a certain experiment it was found that the temperature in a flask containing 100 grams of germinating wheat was 34° F. higher than that in a similar flask containing dead or non-germinating seeds.

Respiration and assimilation are quite independent processes, and it is important to distinguish clearly between them. The chief differences may be stated thus:

RESPIRATION.	ASSIMILATION.
Oxygen absorbed and carbon dioxide given off.	Carbon dioxide absorbed and oxygen given off.
Takes place in all parts of the plant, both day and night.	Takes place only in green parts and in daylight.
Results in loss of dry matter.	Dry matter is gained.
Fouls the air.	Purifies the air.

Effect of too much water in soil.—On water-logged soils, the roots of plants rot a short distance below the surface. This is not because the excess of water is in itself harmful to the roots, but because under such conditions the roots are unable to obtain oxygen for respiration. When rain water first passes into the soil there is dissolved in it a considerable amount of air. This air, however, is soon used up and the water becomes stagnant. Draining water-logged soil removes the stagnant water, and so allows air and fresh water to enter the soil; thus the roots are supplied with oxygen, and healthy growth is possible.

EXERCISES.

PRACTICAL.

1. Fill two bottles each about half full with the creeping shoots of white clover and cork tightly. Place them both in the dark for two days. Test the air in one bottle for carbon dioxide with lime-water (page 65), and into the other bottle lower a lighted taper. Note that the lime-water turns chalky and that the taper is extinguished. Now seal the bottles and stand in the light for two days, and again test the air. Observe that, in the dark, respiration alone takes place; while in the light, assimilation also goes on.

2. Grow two pots of mustard. When the plants have become established let one pot stand in water so that it is about half immersed. Keep the soil in the other pot moist merely, not saturated with water. Compare the growth in the two pots.

3. Repeat Expt. 2, page 65, using two similar leaves in separate tubes. Tie a piece of brown paper over one of the tubes, and compare the amounts of water collected in the two tubes.

4. Steep about 100 grams of wheat in water for about 24 hours, then put them into a thermos flask. With a piece of wire or string lower into the flask a test-tube containing a strong solution of caustic potash. This is for the purpose of absorbing the carbon dioxide given off by the germinating seeds. Insert a thermometer into the flask, and close the mouth of the flask with a plug of cotton-wool.

Set up a similar experiment, only using this time, seeds that have been killed by steeping in boiling water for about 5 minutes.

Keep both flasks together, at as uniform a temperature as possible, and every day compare the temperature of the growing and the dead seeds. After some time the temperature of the dead seeds may also rise owing to the growth of moulds. The experiment should then be stopped.

WRITTEN.

1. Describe an experiment to show that the leaves of plants transpire. How is transpiration influenced by (*a*) bright light, (*b*) dull, damp weather, (*c*) warmth?

2. Of what benefit is transpiration to the plant? In what circumstances is transpiration harmful? Give an example of how the farmer or gardener prevents his crop being injured by excessive transpiration.

3. Why is cropped land drier than similar land uncropped?

4. Why do hedgerow trees cause more damage to the crop in dry than in wet seasons?

5. What sort of weather is most suitable for transplanting cabbages, and why?

6. Describe experiments to show that growing plants require air. What changes do they bring about in the air?

7. Explain why the drainage of water-logged soils improves the health of the crops.

8. At what stages is respiration most active in plants? Explain why a heap of mangels does not contain as much dry matter in March as in the previous September.

9. Describe experiments to show that in the dark a living plant fouls the air as an animal does; but in the light it purifies the air again.

CHAPTER VIII.

CONSTITUENTS OF SOILS.

PRACTICAL WORK.

1. Put about one teaspoonful of soil into a wide test-tube. Fill the tube three parts full of water, and boil gently for five minutes. After the mixture has cooled, shake thoroughly and allow to stand for ten minutes.

Notice that in the process of settling, the soil particles are more or less sorted, and deposited in layers at the bottom of the tube. The coarse particles, made up of small stones and large grains of sand, settle immediately; upon these a layer of small sand grains is deposited, and, finally, a layer of mud settles on the top of the sediment. The finest particles do not settle in this time, but remain suspended in the water, and give to the latter a muddy appearance.

Now shake the tube, and allow to settle for one minute. Then pour off the muddy liquid into a basin, without letting any of the sediment pass over. Add more water, shake, and again, after one minute, decant the turbid liquid.

Repeat this, until, after one minute's standing, the water is clear. In this way the soil has been separated into (1) coarse material (stones and sand) in the test-tube, and (2) fine material (clay) in the basin.

Both the sand and clay will be required later.

Wash the sand on to a plate, pour off the water, and allow the sand to dry. Let the muddy liquid in the basin stand for a day or two, then pour off as much of the water as possible and dry the residual clay.

2. Put about a teaspoonful of dark-coloured soil into a crucible, or tin lid, and heat over a flame until no further change can be seen in the appearance of the soil. The decaying vegetable matter contained in the soil is burnt away. Allow the soil to cool. In what way has its colour changed?

3. To a little chalk, limestone, or lime mortar scraped from a wall, add dilute hydrochloric acid. Notice the brisk effervescence that takes place owing to the presence of large amounts of carbonate of lime. In the same way, test samples of several local soils for lime by placing a few grams of fine soil in a dish and treating with hydrochloric acid. Look carefully for a slight effervescence.

In our study of the plant we have seen that it obtains water and part of its food from the soil. Air must also be present in the soil to provide for respiration, and growth only takes place if the soil is above a certain temperature.

The farmer sometimes describes a soil as being wet or dry, poor or rich, cold or warm, thus indicating that soils vary with respect to their power of supplying water, food, and heat to the plant. We have now to consider some of the causes of these differences.

Large and small particles in soils.—If a little soil be well shaken up with water in a test-tube and allowed to stand, the soil particles settle more or less in layers; the largest particles at the bottom, finer above, and the finest at the top, or still in suspension in the water. The separation is very incomplete, a certain amount of fine material being mixed throughout the coarse. It is sufficient, however, to show that the soil is composed of particles of various sizes. If several kinds of soil are treated in this way, marked differences will be found in the proportion of fine and coarse material present.

Separation of sand and clay.—A more thorough

separation may be made as follows: about a pint of soil is spread out on a piece of paper and allowed to stand until no further change of colour indicates that it is air-dry. Any lumps present are broken up before they are quite dry. This dry soil is then passed through a sieve made by replacing the bottom of a wooden box by a piece of perforated zinc with holes $\frac{1}{8}$ inch in diameter. The stones are retained on the sieve, and what passes through is termed **fine earth**. It is this fine earth with which we are now concerned.

About 20 grams of the fine earth are weighed and boiled for half an hour in a porcelain basin. The boiled soil is then washed into a beaker having a mark on the side, 7·5 cm. from the bottom. The beaker is filled with water to the mark, its contents well stirred, and then allowed to stand for exactly one minute. The muddy liquid is then gently but quickly poured off into a large vessel. The beaker is again filled with water to the mark, stirred, and allowed to settle for one minute, and the muddy liquid again decanted off. This operation is repeated until, after standing for one minute, the water is quite clear. The gritty sediment remaining in the beaker is now washed on to a sieve of 100 meshes to the inch, and the finer particles washed through into a basin.

The fine earth has now been divided into three fractions: (1) coarse sand on the sieve, (2) fine sand in the basin, and (3) very fine material, which we will call clay, in the large vessel.

After standing a few moments, the clear water is poured off the fine sand. The coarse and fine sands are allowed to dry, and are then weighed. As the clay is more difficult to collect and weigh than the sands, the amount is best determined by calculating the difference between the sum of the coarse and fine sand and the weight of fine earth originally taken.

Twenty grams of soil treated in the way described gave the following results:

		Per cent.
Coarse sand - - -	5·6 grams	= 28.
Fine sand - - -	8·3 ,,	= 41·5.
Clay (by difference) -	6·1 ,,	= 30·5.
	20·0	100

This is a rough mechanical analysis of a soil. A sandy soil, a sandy loam, and a clay loam were each separated

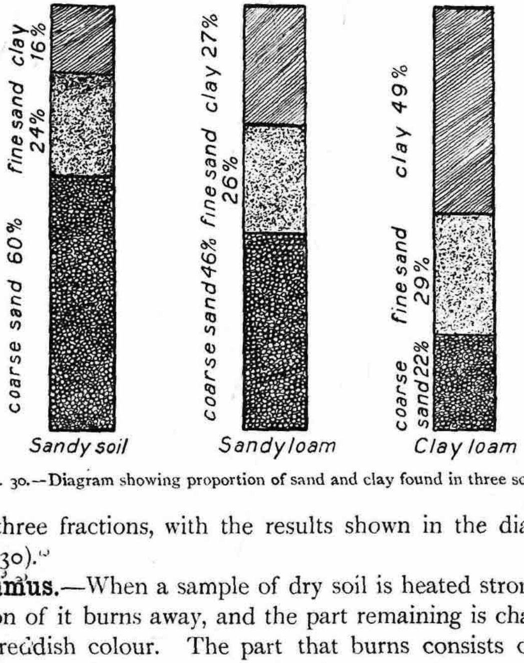

FIG. 30.—Diagram showing proportion of sand and clay found in three soils.

into three fractions, with the results shown in the diagram (Fig. 30).

Humus.—When a sample of dry soil is heated strongly a portion of it burns away, and the part remaining is changed to a reddish colour. The part that burns consists of the decaying remains of plants, and is known as **humus**. It is black or dark-brown in colour, and the dark colour of soils is chiefly due to its presence. Hence soils become lighter

in colour—usually reddish—when the humus is burnt away. As a rule, the blacker the soil the more humus it contains.

Lime in soil.—In a chalky soil many of the mineral fragments separated as sand or clay may consist of carbonate of lime or chalk. In other soils the amount of carbonate of lime present is usually very small; but it is such an important constituent that it requires special consideration.

There are many forms of lime; but in the soil, lime occurs chiefly as carbonate of lime or chalk. Quicklime and slaked lime when applied to the soil become quickly converted into carbonate of lime. When the farmer speaks of "lime" he means carbonate of lime, or a form of lime such as quicklime, which becomes changed into carbonate of lime in the soil. It is in this sense that the term "lime" will be used here.

When dilute hydrochloric acid is added to carbonate of lime a brisk effervescence takes place. If, when a soil is thus treated, there is no effervescence, lime is absent, or present only in very small amount.

Classification of soils.—The majority of soils consist of a mixture of sand and clay, with some stones, from 2 to 10 per cent. of humus, and up to 1 per cent. of carbonate of lime. If there is a large proportion of sand, the soil is described as **sandy**; as the proportion of clay in the soil increases it is described as **sandy loam**, **loam**, **clay loam**, and finally, as a **clay** soil if it contains sufficient clay to give to the mass of soil, distinct clay-like properties. Even in what is described as a stiff clay soil there is a considerable amount of sand, or it would be impossible to cultivate it.

The character of these soils, consisting mainly of sand and clay, may be modified by the presence of unusually large amounts of stones making a **gravelly soil**, or of lime forming a **calcareous** or a **marly** soil. If humus accumulates, a **peaty** soil is formed.

The types of soil mentioned pass gradually one into the

other. Between a clay and a sandy soil tl[...] difference; but opinion may differ as to wh[...] soil should be described as a sandy soil or [...]

EXERCISES.

PRACTICAL.

1. Make a mechanical analysis of different t[...] and subsoils in the way described in this ch[...] your results without weighing the clay, but a[...] stand for a few days, then pour off as mucl[...] possible and dry the clay. Put the coarse sar[...] clay into small bottles, and attach labels giving[...]

A sieve of woven brass wire having 100 mes[...] inch is required for the separation of the coarse[...]

2. Weigh out 10 grams of soil and subsoil re[...] an old pasture field. Dry in the water oven; rew[...] respectively until the humus is burnt away. Fi[...] the loss of weight on heating. What conclusi[...] as to the comparative amounts of humus conta[...] *subsoil?*

WRITTEN.

1. Explain how you *could obtain a few pounds* [...] from the soil of a tillage field.

2. How would you test for lime in a soil?

3. What is humus? How does it *influence the* [...] soil?

4. Of what substances are soils composed? [...] ordinary classification of soils based upon the pr[...] these substances present.

5. Why is the top soil in a field usually darker th[...] soil? What change in colour takes place when a l[...] is buried, and to what is the change due?

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in Question 2, using sandy soil, or sand from a sandpit, instead of clay. Write down what happens in each case as compared with the clay.

Clay is made up of extremely small particles. When suspended in water these fine particles do not fall to the bottom quickly as grains of sand would do, but remain floating in the water and give to the latter a muddy appearance. When moistened and rubbed between the fingers, clay feels soft and greasy. Moist clay is sticky;

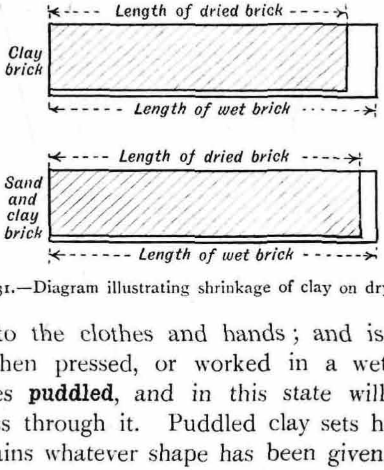


FIG. 31.—Diagram illustrating shrinkage of clay on drying.

it adheres to the clothes and hands; and is difficult to remove. When pressed, or worked in a wet condition, clay becomes **puddled**, and in this state will not allow water to pass through it. Puddled clay sets hard on drying, and retains whatever shape has been given to it when moist.

Clay shrinks on drying; the outside lines of Fig. 31 represent the sides of two oblong bricks made of (*a*) clay, and (*b*) sand and clay. The shaded portions represent their size when dry. The clay brick shrank from 10 cm. to 9·1 cm., and the sand and clay brick from 10 cm. to 9·5 cm.

Effect of lime on clay.—A little yellow clay was shaken up with water and the turbid liquid poured into two

cylinders. To one cylinder a pinch of slaked lime was added. After one hour the photograph (Fig. 32) was taken.

The clay in the vessel to which the lime was added has settled to the bottom, and the water above is quite clear. In the other cylinder the water remains turbid.

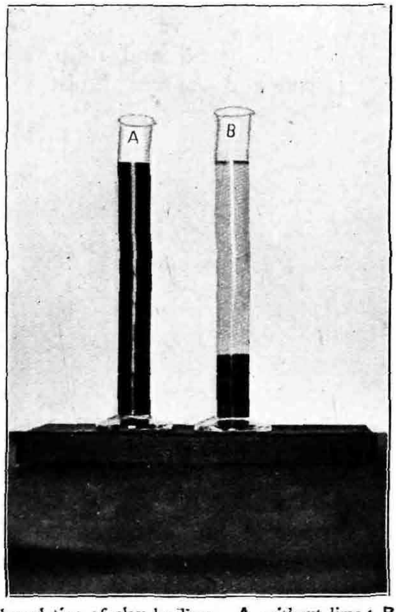


FIG. 32.—Flocculation of clay by lime. **A**, without lime; **B**, with lime. Where lime was added the clay has settled quickly.

The addition of lime, or of lime-water, causes the suspended clay particles to become grouped into crumb-like compound particles, or flocks. These, being much larger and heavier than the single particles, sink, and the water clears quickly. The clay is said to be **flocculated.** In this condition it is less sticky, does not shrink so much on drying, allows water to pass through much more freely,

and generally is more sand-like in its properties. A clay brick made with lime-water instead of rain-water does not shrink so much on drying, and when dry is more easily broken down.

Clay may also be flocculated by frost and exposure to weather.

Effect of burning clay.—When clay is burnt its character is entirely changed. A piece of hard, dry clay becomes soft and greasy when moistened, but if the clay is burnt in a fire, a brick is formed which cannot be rubbed down into a greasy paste, and however fine it is ground does not form clay again.

Sometimes clay and vegetable refuse are mixed together and slowly burnt in heaps on the field. The burnt clay is then spread over the land, and has the effect of making more sand-like the clay soil upon which it is spread.

Sand.—Sand consists of comparatively large grains. It feels hard and gritty; and when shaken up with water, the grains quickly settle, and do not float in the water like clay particles. Wet sand is somewhat sticky; but it does not become puddled however much it is pressed or kneaded; and when dry it becomes quite loose again. Sand dries quickly.

Humus.—Humus is decaying organic matter, chiefly plant refuse. It is black, or dark-brown, in colour, and may be burnt almost completely away. One of its most valuable properties is the large amount of water it will absorb. Its influence in this way, and also as an important source of plant food, will be considered more fully later. Humus greatly improves the character of both sandy and clay soils. The latter are made more loose and friable, and less difficult to work. On the other hand, humus makes the grains of sand in a sandy soil stick together better, so that the soil is less loose. Humus also makes sandy soils cooler and more retentive of water.

Sandy and clay soils compared.—The farmer describes a clay soil as "heavy," and a sandy soil as "light"; but as a matter of fact a cubic foot of sand weighs much more than a cubic foot of clay, so that the farmer cannot be referring to the weight of the soils. It is the stickiness and tenacity of the clay soil, making it heavy to work, that causes him to speak of it in this way. More horses are required to cut and turn the furrow in ploughing a clay than are necessary when ploughing a sandy soil. After a spell of wet weather the farmer may plough or cultivate his sandy fields almost at once without injury to the land; but if he works his clay land before it has reached a certain stage of dryness, it becomes puddled, and sets so hard when dry that it is almost impossible to break it down by tillage implements into the "crumby" condition required for a good tilth.

A clay soil should not be worked down into a very fine condition, or it will be liable to be puddled by rain. Clay soils shrink considerably during a long drought; but as a 10 acre field cannot contract to say $9\frac{3}{4}$ acres, a series of deep cracks are formed by small areas of soil shrinking in opposite directions. In this way, roots of plants may be torn asunder and the crop considerably damaged. On the other hand, these cracks may be beneficial to the land by allowing air into the subsoil, and, later, by promoting drainage.

Clay soils are improved greatly by the application of lime, which flocculates the clay. The clay flocks formed in the soil act in many respects like grains of sand. Hence the soil is ploughed more easily, and requires less labour to form a good seed bed. As frost causes clay to flocculate, it is important that clay land be ploughed early and left exposed to the action of frost during the winter months.

EXERCISES.

PRACTICAL.

1. To each of two jars or beakers full of distilled or rain-water, add a little clay and stir well. Now add to the muddy liquid in one of the jars a pinch of quicklime, or a little lime-water. Stir, allow the jars to stand, and note that in the jar receiving lime the clay particles form crumb-like clusters or flocks. Which jar clears more quickly?

2. Make two bricks, of the same size, of moist clay; the dry clay in one case being made into a paste with distilled or rain-water, and in the other case with lime-water. Measure the bricks when wet and again when dry; which of the dry bricks is more easily broken down?

3. Over about 6 inches square of rough board or stone, plaster puddled clay about $\frac{1}{4}$ inch thick. Describe exactly what happens when the clay dries.

4. Moisten samples of peaty and other soils, and let them remain in contact with red and blue litmus papers for a few minutes. How does it affect the colours of the papers? Try the effect of acid (*e.g.* vinegar) and of alkalies (*e.g.* lime) on the papers. What conclusion do you draw as to the nature of the soils you have tested?

WRITTEN.

1. If you work a clay soil when wet, how will its behaviour be affected (1) as regards rain falling on the land, (2) as regards its cultivation when dry?

2. What is clay and how does it differ from sand? What is the effect of (*a*) adding lime to clay, (*b*) burning clay?

3. What differences might you expect to observe on clay and sandy soils respectively under the following conditions: (*a*) after long continued rain, (*b*) after long drought, (*c*) when walking over a ploughed field after rain, (*d*) in the appearance of a newly turned furrow, (*e*) number of horses used for ploughing?

CHAPTER X.

FORMATION OF SOILS.

PRACTICAL WORK.

1. Take two wide test-tubes. Into one put a little old mortar from a wall, and into the other a small piece of limestone or chalk. To both add dilute hydrochloric acid, a few drops at a time, until they cease to effervesce. Filter, and compare the nature of the insoluble residues left in each case. Soil water also acts as a weak acid, and slowly dissolves certain parts of rocks, leaving the more insoluble material behind.

2. Fill a narrow-necked bottle with water and leave it outside overnight during a severe frost; or place the bottle in a freezing mixture of salt and ice. The water expands on freezing and bursts the bottle.

After a spell of frosty weather notice the soft, crumbling condition of the outside of certain bricks in walls. Can you suggest the reason for this?

3. In a field, dig a hole about two feet deep. How does the soil near the surface differ from the deeper soil, particularly with respect to (*a*) colour, (*b*) hardness, and (*c*) size of particles?

Sedentary soils.—Fig. 33 is a photograph of a limestone quarry. Notice that, at the base, the solid rock is split up into huge blocks by horizontal and vertical joints, or cracks. Passing upwards we see the cracks gradually becoming more numerous, until a part is reached where the rock material is quite loose and shattered; here plant roots

are found growing between the cracks. The rock now shades into a mixture of stones and soil, and about 9 inches from the top there is the soil proper, which is distinguished from the subsoil chiefly by its darker colour. It is evident that the soil has been formed by the gradual disintegration of the rock below. A soil formed in this way is termed a **sedentary** soil.

Photo Spencer, Richmond, Yorks.

FIG. 33.—Section of limestone quarry, showing gradual passage of rock into soil; near Richmond, Yorks.

In addition to sedentary soils which have been derived from the rock immediately underneath, there is a second class of soils termed transported or **drift** soils. These have been formed from rock débris which has been conveyed by running water, by ice, or by wind, and deposited in their present situation.

The alluvial soils found on the low flat land bordering on rivers, and the soils on the Boulder Clay which covers large areas in Scotland and the North of England, are drift soils formed from material that has been conveyed by water and ice respectively.

Weathering agencies.—All soils, both sedentary and drift, have been derived from rock by the process termed **weathering.** The chief weathering agencies are frost and water.

Frost.—Water expands on freezing, ten volumes of water becoming nearly eleven volumes of ice. This is why water-pipes are burst during frosty weather; though the damage is not usually discovered until the thaw sets in. When water in the joints and cracks of rocks becomes frozen, it acts as a wedge, enlarging the cracks and splitting up blocks which, by successive frosts, become broken into smaller and smaller fragments. The pulverizing action of frost is taken advantage of by the farmer, who ploughs his stiff clay land in autumn, leaving it rough so that it may be broken down by alternate freezings and thawings during the winter.

Water.—Not only in freezing, but in other ways does water act as a weathering agent. Consider the part water has played in the formation of the soil over the rock of the quarry (Fig. 33). The limestone rock consists of carbonate of lime with some clay as an impurity. Carbonate of lime is practically insoluble in pure water, but it is soluble in water containing carbon dioxide. In its passage through the air and soil, rain-water becomes charged with carbon dioxide, and in this way the carbonate of lime has been dissolved out of the rock near the surface, leaving the insoluble clay behind. This clay, together with larger rock fragments and decaying vegetable matter (humus), forms the soil. The water, in the district where this quarry is situated, is **hard**; so that the kettles become coated with carbonate of lime (fur), which has been deposited from the water which has passed through limestone rocks into the local springs.

Many other rocks besides limestone contain carbonate of lime, or other minerals, which may be dissolved out in the same way.

Water, with its dissolved gases, causes some rocks to

become discoloured and rotten, just as a knife-blade kept wet is ultimately converted into red rust.

By the continued action of frost and water, and, to a less extent of other agencies, rock is broken up into stones, sand, and clay, and either remains on the rock surface or is carried away and deposited elsewhere. Upon this material plants establish themselves; the roots push in between the crevices of the rock; the carbon dioxide given off in respiration increases the weathering effect of the soil water; and the decaying of the plant adds humus to the soil and provides food for new generations.

At a later stage, the weathering agencies described above are assisted by the work of earthworms, moles, and other animals that live in the soil, and by the tillage operations of the farmer.

Soil and subsoil.—The soil a little below the depth to which it is usually cultivated differs in appearance from the soil above, and is known as the **subsoil.** Sometimes the soil and subsoil are very similar (except that the latter is harder and lighter in colour), and the change from subsoil to soil is quite gradual. But more often the distinction is very marked, the loose brown soil passing suddenly into clay, sand, gravel, or solid rock.

As a rule the subsoil is not capable of growing crops. If the farmer wishes to deepen his soil he ploughs up just a little of the subsoil in the autumn. This subsoil is exposed during the winter to the action of frost and other weathering agencies, and in the following spring it becomes incorporated with the soil. If much of the subsoil were brought to the surface at one time, it might be impossible to grow crops on the land for many years.

EXERCISES.

WRITTEN.

1. Describe carefully some section of soil and subsoil which you have seen in a quarry or railway cutting, illustrating your remarks by a sketch. What does this section teach as to the manner in which a soil may be produced?

2. Of what substances is soil composed, and how does it come into being? Describe the processes which are always at work making soil.

3. What are the effects of frost on soil? Which soils does frost benefit most, and why?

4. Stones may often be seen to crumble after frost; why does this happen, and why do some stones crumble more than others?

5. Heavy traffic (*e.g.* a traction engine) is much more injurious to roads just when they have thawed after a spell of frost than at any other time. Explain the reason for this.

6. Land may be injured by ploughing it too deeply: explain why. How should the farmer proceed to deepen the soil of a field that is liable to be damaged by deep ploughing?

CHAPTER XI.

THE RELATION OF SOILS TO WATER.

PRACTICAL WORK.

1. Obtain three lamp chimneys of exactly the same size and of the shape shown in Fig. 34. Make a mark with stamp paper 5 inches from the narrow end of each chimney, and over these ends tie a piece of linen. Fill each chimney to the mark with powdered, air-dry (*a*) sandy soil, (*b*) clay soil, and (*c*) peaty soil.

During the filling process keep tapping the bottom of the chimneys on the table, and when filled to the mark see that the soil does not settle further with more tapping. Now fix the chimneys on stands, pour over each a measured quantity of water (about 150 c.c.), and collect the water passing through. The water that passes through pour over a second time; the peaty and clay soils may not get thoroughly wetted the first time. When the soils have ceased to drip, measure the amount of water that has passed through in each case, and calculate the amounts retained.

2. Pour over each of the wet soils 100 c.c. of water, and note the length of time taken for the water to pass through in each case.

3. After the water has ceased to drip from the soil, let the chimneys rest on dry sand, taking care that the linen is in close contact with the sand on one side and the wet soil on the other. Note that the sand becomes wet owing to the passage of more water from the soils, although they had apparently ceased to drain.

4. In a dish of coloured water stand two plates of glass (about 6 inches square) face to face, so that they touch at one side and are separated at the other by a doubled post-card. Note that the closer the plates are together the higher the water will rise.

5. Tie a piece of linen over the end of each of two long lamp chimneys, and fill one with coarse sand and the other with fine sand, or powdered soil. Let the tied ends of the chimneys stand in a dish containing about half an inch of water. Note the rise of water in the soils, and mark with a piece of stamp paper the heights to which the water has risen at the end of three hours, and afterwards every day.

The amount of the crop is more often limited owing to lack of water than to any other cause. We have now to consider some of the reasons why soils differ in respect of their power of supplying water to the plant.

Capacity for retaining water.—Three lamp chimneys with a piece of linen tied over one end were filled with equal volumes of the sandy and clay-loam soils, of which particulars are given on page 75. Another chimney was similarly filled with a sandy peat soil containing about 20 per cent. of humus. Over the soil in each chimney 150 c.c. of water were poured, and the photograph (Fig. 34) was taken when the water from the soils had ceased to drip into the vessels below. Most water has been retained by the peaty soil, less by the clay-loam, and least of all by the sandy soil.

If the bottom of the chimneys are now rested on dry sand, so that the linen is in close contact on one side with the wet soil and on the other with the sand, the latter will gradually become wet owing to the passage of water from the wet soil. Water will continue to drain in this way until a stage is reached at which the soils, though still moist, will not part with any more water to the sand below. They are then in what might be termed a fully drained condition, and can only become drier by evaporation. If the amount of water now held by the drained soils be determined, the greater

water-holding capacity of clay and peaty soils compared with sandy soils becomes much more marked.

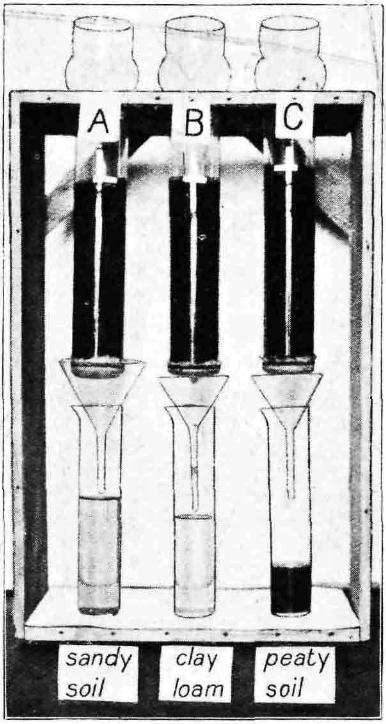


FIG. 34.—Illustrating amounts of water retained by three kinds of soil. An equal volume of water was poured over each soil.

After draining in the way described for five days the soils shown in Fig. 34 retained the following percentages of water per volume of air-dry soil:

	Per cent.
Sandy soil	19
Clay-loam	29
Sandy peat	35

Passage of water through soils.—Equal depths of sandy, clay-loam, and peaty soils contained in three lamp chimneys were saturated with water. After they had ceased

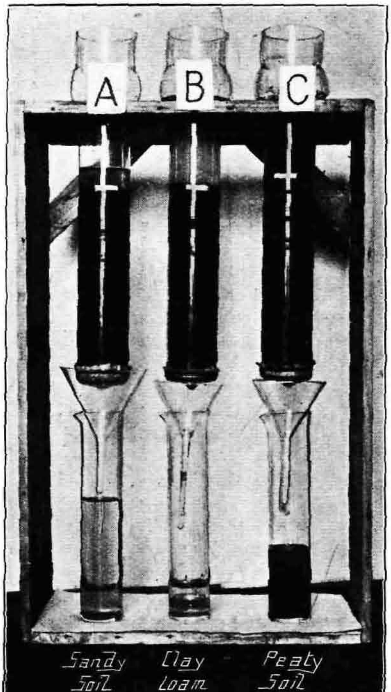


FIG. 35.—Drainage through saturated soils over which equal volumes of water have been poured. Photograph taken after one hour. Very little water has passed through the clay soil.

to drip, 100 c.c. of water were poured over each soil, and the photograph (Fig. 35) taken one hour afterwards. In this time 75 c.c. had passed through the sandy soil, 7 c.c. through the clay-loam, and 42 c.c. through the peaty soil.

Nearly all the water poured over the clay soil is still standing on the surface, while from the surface of the sandy soil the water has almost disappeared.

It is evident that water passes very slowly through clay compared with sandy soils. If the clay be puddled it will allow no water to pass through.

Effect of lime.—As the addition of lime to clay causes *it to become more sand-like in its properties, we should*

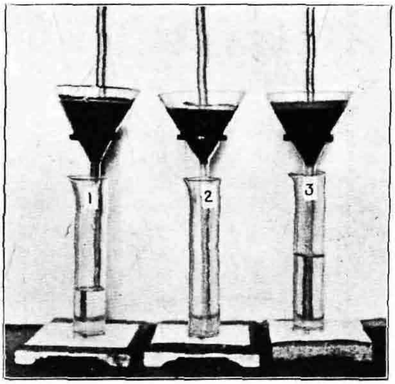


FIG. 36.—Passage of water through clay. 1, untreated clay; 2, puddled clay; 3, limed clay. No water has passed through the puddled clay, and most through the limed clay.

expect that a clay soil to which lime had been applied would allow water to pass through more freely than an untreated clay. Three funnels were filled with equal weights of clay soil. To No. 1 nothing was done; the soil in No. 2 was moistened and pressed (puddled); and in No. 3 a pinch of lime was well mixed with the soil. The surface of each soil was kept covered with water, and after standing for one hour the photograph (*Fig.* 36) was taken. Through the untreated soil 36 c.c. have passed, no water has got through the puddled soil, and 60 c.c. have percolated through the limed soil.

Rise of water in soils.—Soils are not only able to retain more or less of the rain-water that falls upon the ground, but may raise to the surface again, water that has passed into the subsoil. That soil may lift water from below is seen when a plant-pot filled with soil is placed in a saucer of water. The water is slowly absorbed and the surface of the soil becomes moist, though it may be several inches above the level of the water in the saucer.

The same phenomenon may be observed when a piece of school chalk, or a fine glass tube is dipped into water.

Capillarity.—This property of lifting water, possessed by fine tubes and porous substances, is known as **capillarity.** The height to which water rises in a fine tube depends upon the bore of the tube. The finer the tube the higher the water will rise, but the rise will be more rapid in the wider tube.

In the soil, the capillary movement of water takes place both in the minute zigzag passages formed between the particles of soil and over the surface of the moist soil grains.

Just as there are much larger channels formed in a pot filled with marbles than in a pot filled with small shot, so between the larger particles of sandy soil there are much larger passages than between the finer particles of a clay soil.

Three glass tubes 4 feet long were filled with (*a*) coarse sand, (*b*) fine sand, and (*c*) powdered clay, and stood in a shallow tray of water. Fig. 37 is a photograph taken after half an hour, and shows that during this time the water has risen most in the coarse sand and least in the clay.

In the coarse sand the water rose very little after the first few days, but continued to rise, although but slowly, in the fine sand and the clay. Another photograph (Fig. 38), taken six weeks later than the first, shows that the level to which the water has risen is highest in the clay, not quite so high in the fine sand, and lowest in the coarse sand.

We see, then, that coarse sand is able to raise water

quickly through a short distance, and that fine sand and clay will lift water more slowly but to a greater height.

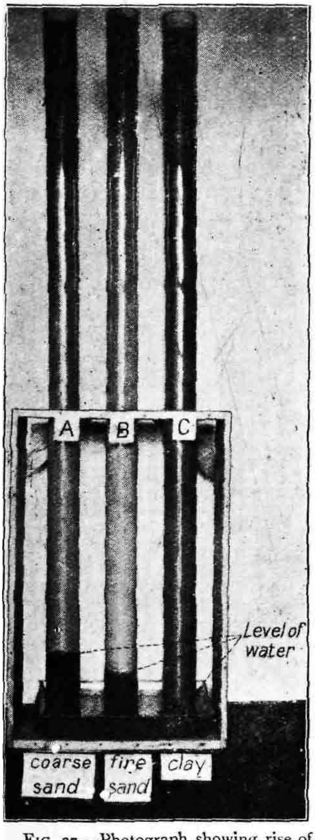


FIG. 37.—Photograph showing rise of water by capillarity in 30 minutes. It has risen quickest in the coarse sand.

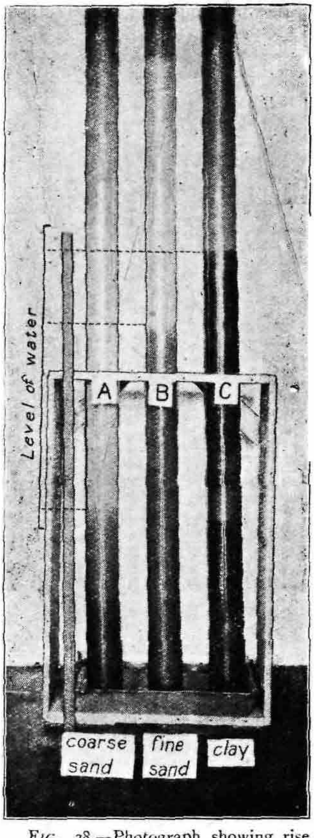


FIG. 38.—Photograph showing rise of water in six weeks. It has risen highest in the clay.

Influence of cultivation on soil moisture.—Besides losing water by drainage, the soil loses water by evaporation

from its surface, and, during dry weather, this greatly reduces the amount of water available to the plant. The experiment illustrated in Fig. 39 shows how the state of the soil influences the movement of soil water and the amount lost by evaporation.

The soil in the pots was first saturated with water, and afterwards kept moist by means of lamp wick extending about half-way through the soil and dipping into water below. Water was filled to the same level in each bottle. The top inch or so of the soil in one pot was kept loose and crumby. In the other pot the soil was kept firm. The surface of the firm soil was always moist, even in the driest weather. Now in this soil there are an enormous number of capillary passages extending to the surface from the wet soil below. They are fine enough to lift the water the required height, yet not too fine to prevent it rising freely, and so water is raised to the surface as rapidly as it is evaporated.

In the stirred soil these fine passages do not continue to the surface, but are largely replaced in the loose soil by channels too wide to raise water any distance. Hence water does not pass into the loose soil, and it becomes dry. This layer of dry soil then serves to protect the moist soil below from the drying effects of sun and wind.

The sketch (Fig. 39) was made after the soils had been exposed to the sun and wind for one day, and shows that much less water has been removed from the bottle under the stirred soil than from the bottle under the soil which has been kept firm.

We conclude that compressing the soil, by rolling or other means, brings the water to the surface, but is wasteful of the water in the deeper soil. Stirring the soil by harrowing or hoeing causes the surface to become dry, but by preventing evaporation decreases the loss of water from the subsoil. Gardeners sometimes cover the ground with straw, or similar

material, for the same purpose. Such a covering is known as a **mulch.**

It is not practicable for a farmer to cover a field of mangels, for instance, with a layer of straw to hinder evaporation. But so long as it is possible for him to work

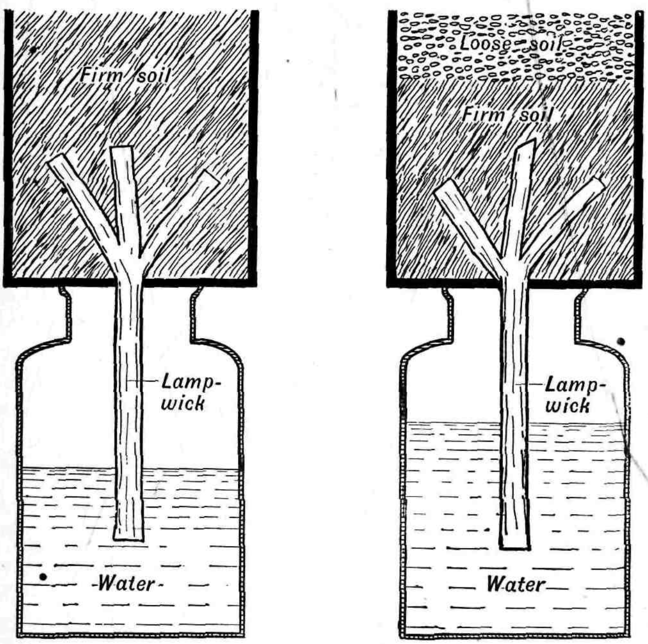


FIG. 39.—Experiment to show that water is saved by keeping the soil loose on the surface.

the horse-hoe between the drills, by frequent hoeings he keeps the top few inches of soil loose. This loose soil serves as a mulch, and prevents the moisture from the subsoil being wasted by evaporation. The water so saved may be of immense benefit to the crop.

Water-logged soils.—The space between the soil

grains capable of being filled with water, or air, is termed the **pore space.** The amount of pore space in soils varies from about 30 per cent. in coarse sandy soils to 50 per cent. in clay soils. After heavy rain this pore space may become filled with water, but in a well-drained soil most of the water soon drains away and is replaced by air. In such a soil, water will only be retained in the finer passages, and as a film coating the surface of the soil grains; the larger spaces will contain air.

If, owing to the situation of the soil or the nature of the subsoil, the excess of water cannot drain away, then the soil becomes **water-logged.** In this condition the roots of plants cannot obtain the air necessary for respiration, and many other changes requiring the presence of air in the soil are prevented.

Summary.—Clay soils and soils containing much humus retain most, and sandy soils least, of the rain-water that falls on the ground. As water moves so slowly through a clay soil, pools of water often collect on the surface, especially if it has been puddled by the treading of cattle or in any other way.

As the water retained by the soil is removed by the roots of plants and by evaporation, more water is raised by capillarity from the wetter soil below. A sandy soil is able to raise water in this way more quickly than a clay soil, but to a less height, so that unless there is a supply of water a short distance below the surface, crops on sandy soils soon suffer for lack of water.

On the other hand, whilst a clay soil is able to raise water to a considerable height, the movement is so slow that it may not be brought to the roots of plants in sufficient quantities. During long periods of dry weather, crops on these extreme types of soil are most likely to suffer.

Rolling the soil brings the moisture to the surface. For this reason the farmer rolls the land after sowing small

seeds, such as grass and clover, which must be covered with very little soil. If the land were left unrolled, the layer of soil near the surface might be too dry for the germination of the seed and the growth of the young seedling.

Harrowing and hoeing form a soil mulch on the surface which preserves the store of moisture below from evaporation. The water saved in this way may be of great benefit to the crop during a dry summer.

Healthy growth is impossible on a water-logged soil. It is only by draining that such a soil can be made fertile.

The water-retaining capacity of sandy soils may be improved greatly by increasing the amount of humus in the soil. This may be done by applying farm-yard manure, or by growing a crop such as mustard, and then ploughing it in. Leaving land in grass for a few years also adds to the store of humus in the soil.

EXERCISES.

PRACTICAL.

1. Fit up the apparatus shown in Fig. 39, using glazed pots, or ordinary 6-inch plant-pots painted with brunswick black to prevent evaporation from the porous earthenware, and two or three wide pieces of lamp-wick. That portion of the wick inside the pots should be slit lengthwise into several strands. See that the wick is thoroughly wetted before putting through the pots. Strips of flannel may be used instead of lamp-wick. Keep the soil in one pot firm, and in the other let the top 2 inches be kept loose. This loose layer should be "nobby" and dry or it does not form a mulch. Compare the amounts of water taken up from the bottles in each case. In what kind of weather is the difference most marked? Later, check your results by making the firm soil loose and the loose soil firm.

2. Find the exact volume of a pot (300 to 500 c.c.) by filling it to the brim with water and measuring the quantity used. Empty out the water and fill the pot with dry sand or sandy soil, tapping the pot on the table during the filling process.

With a ruler strike the soil off level with the brim of the pot. Now very slowly add a measured volume of water until it ceases

to sink into the soil. From the volume of water absorbed calculate the percentage of unoccupied space, or pore space, in the dry soil. Thus: a pot holding 500 c.c. after being filled with soil held 200 c.c. of water.

$$\text{Pore space} = \frac{200 \times 100}{500} = 40\ \%.$$

This is a very rough method of determining the pore space, and the result will be too low.

WRITTEN.

1. Compare sandy and clay soils with respect to (*a*) their power of retaining rain-water, (*b*) the rate at which they allow water to pass through them, and (*c*) their power of raising water from below.

2. What is meant by the pore space in soils? In what conditions of the pore space is plant growth prevented?

3. During dry weather what is the effect of harrowing and rolling respectively upon (*a*) the amount of water near the surface of the soil, and (*b*) the amount of water in the deeper parts of the soil?

4. What substance in the soil has the highest water-retaining capacity? By what practical methods may the water-holding power of the soil be improved?

5. On clay soil what is the effect upon the passage of rain-water into the drains of (*a*) working the soil when wet, (*b*) applying lime to the soil? Describe an experiment that would show the effect of each of these methods of treatment.

CHAPTER XII.

SOIL TEMPERATURE.

PRACTICAL WORK.

1. On a sunny day thoroughly mix up some soil, and put it into two wooden boxes, each about 18″ × 12″ × 6″ (*e.g.* "life-buoy" soap boxes). Make the soil moderately firm. Prop one box up facing south, at an angle of about 20° with the horizontal; and the other facing north, inclined at the same angle. Take the temperature of the soils at 2 inches below the surface at the commencement of the experiment, and every two hours, or other convenient intervals, throughout the day.

Plot your results on a piece of squared paper. What is the effect of aspect upon soil temperature? See that one box is not more exposed to wind than the other, or the cooling effect of evaporation may obscure the heating effect of the sun's rays.

2. Into two weighed beakers weigh out 50 grams of soil and 50 grams of water respectively. Take the temperature of both soil and water. Heat a large beaker of water to a temperature about 30° C. higher than that of the soil. Pour some of this hot water into the soil and stir the mixture with a thermometer until the temperature of the soil is raised by 20° C. In the same way raise the temperature of the cold water by 20° C. These operations should be done quickly. Now weigh both beakers, and calculate how much hot water has been added in each case.

Compare the amounts of hot water required to raise the temperature of equal weights of soil and water by 20° C.

The hot water is used merely as a means of supplying heat.

3. Tie a piece of linen round the bulb of a thermometer. Saturate the linen with water at the same temperature as the air of the room. Note the temperature. Now whirl the thermometer rapidly, or blow on it with a bellows for a few moments, to cause the water on the linen to evaporate rapidly, and again note the temperature. What effect has evaporation had upon the temperature of the linen and thermometer bulb?

4. Over each of two patches of soil, about one square yard in area, sprinkle soot and whitening respectively. Make the soil firm on the surface, and put on just sufficient soot and whitening to make one patch distinctly dark coloured and the other white. Take the temperature of the soil of the centre of each patch, (*a*) on the surface, and (*b*) 3 inches deep, at convenient intervals—say every two hours. Plot on squared paper the results you get on a bright day, and on a dull day.

5. Push a thermometer into a heap of stable manure, and compare the temperature of the manure with that of the air in the shade.

Plant growth will not take place unless the soil is above a certain temperature, and the growth will be most vigorous if the soil is distinctly warm, *i.e.* between 70° F. and 90° F.

Influence of slope on soil temperature.—If the sun at midday shone vertically downwards, level land would receive most heat from the sun; but as the sun is always in the south at midday in this country, land on a southern slope, *i.e.* facing the sun, receives more heat than land on the flat, and much more than land on a northern slope.

In Fig. 40 let the horizontal line represent a level field upon which fall 10 beams of sunlight of equal size. Now imagine the field tilted so that it has a south aspect. The field now receives 11 beams. Tilted in the other direction, as on a northern slope, it intercepts 8 beams only.

Influence of colour.—Dark-coloured substances absorb more of the sun's rays than light-coloured substances. It is for this reason that light-coloured clothing is so much cooler in bright, hot weather than similar material in dark colours. Other things being equal, the darker the soil the more rapidly it becomes warm.

On a bright day two patches of garden soil were covered lightly, one with soot and the other with whitening, and the

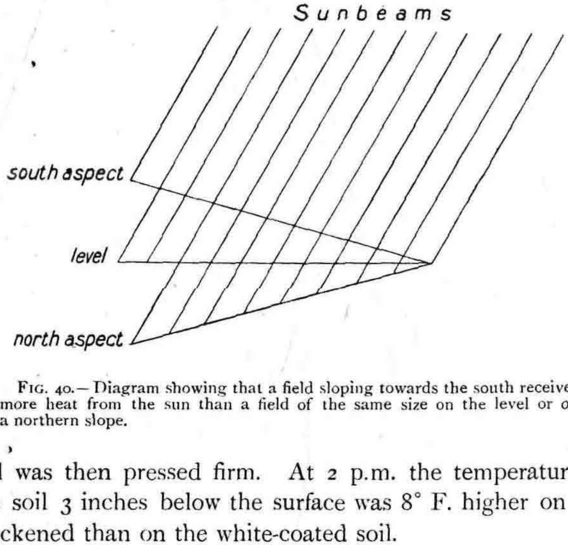


FIG. 40.—Diagram showing that a field sloping towards the south receives more heat from the sun than a field of the same size on the level or on a northern slope.

soil was then pressed firm. At 2 p.m. the temperature of the soil 3 inches below the surface was 8° F. higher on the blackened than on the white-coated soil.

Influence of water content.—The amount of water in the soil is by far the most important factor influencing the soil temperature. An amount of heat that would raise the temperature of 1 lb. of dry soil by 5° to 7° F. would cause a rise of only 1° F. in 1 lb. of water. Hence, the drier the soil the more rapidly it becomes warm.

The cooling effect of evaporation is another reason why wet soils are colder than dry. If the inner side of the wrist,

having been previously wetted, be blown on, the feeling of cold produced will be much greater than if the wrist had been dry.

When water is converted into water vapour, heat must be supplied from external sources. In the instance given, heat is withdrawn from the skin, which becomes colder.

Another example of the cooling effect of evaporation is seen in the fact that the wet bulb of a wet and dry bulb thermometer usually reads much lower than the dry bulb. The drier the air, the greater the amount of evaporation, and therefore the greater the difference in temperature between the two bulbs.

The heat required to evaporate 1 pint of water from the soil is sufficient to raise the temperature of over 5 pints of ice-cold water to boiling-point. It is clear, therefore, that if the excess of water in the soil has to be removed by evaporation, instead of by drainage, a large amount of heat will be wasted, and such a soil will be much colder than if well drained.

Shelter of any kind, by reducing evaporation, makes the soil warmer.

Late and early soils.—The farmer describes stiff clay and undrained soils as *cold and late*, in distinction to sandy and gravelly soils, which, owing to their lower water content, are *warm and early*. The drier condition of sandy soils enables them to be got into a fit state for sowing early in the season, and, with favourable aspect and season, earlier crops will be produced. Hence, potatoes and other crops can be got into the market before the general crops are ready. Crops on these early soils are liable to suffer from drought in summer, and to ripen before they have reached their full growth.

Influence of farm-yard manure.—Heat is produced whenever vegetable matter decays. In a certain instance, when the temperature of the air was at freezing-point, a heap

of rotting farm-yard manure had a temperature of 113° F. at a level of 6 inches below the surface. Exactly the same amount of heat is produced whether the manure rots in the heap or after being ploughed into the soil. In the latter case, however, the heat is distributed over such a large area that we do not notice any appreciable increase in the temperature of the soil. In a garden, where large quantities of manure are sometimes used, the temperature of the soil may be appreciably increased in this manner.

EXERCISES.

PRACTICAL.

1. Fill two boxes with well-mixed dry soil. Saturate one of the soils with water at the same temperature as that of the soils. Expose the boxes, in a windy place if possible, and note the temperature of each soil at 3 inches deep, and of the air above, at intervals, for several days.

Plot your results on squared paper. How does the amount of water in the soil affect its temperature when the temperature of the air is (*a*) rising and (*b*) falling?

Clay soils are often warmer than sandy soils in autumn. Do your results in the above experiment suggest any reason for this?

2. A day or two after heavy rain has fallen, compare the temperature of the soil 3 inches deep at the top of, and at the bottom of (*i.e.* between), potato drills.

WRITTEN.

1. Explain why the temperature of the soil is influenced by the amount of water it contains. How may a cold, wet soil be made warmer?

2. What influence has the colour of the soil upon the amount of heat it absorbs from the sun? Although moory or peaty soils are darker in colour than sandy soils, they are usually cooler. Why is this?

3. A field receives most heat from the sun when the sun's rays strike the surface of the field at right angles. Show by a diagram that if the sun's rays are inclined at an angle of x° to

the horizontal, then a field sloping ($90 - x^\circ$) to the south receives the maximum amount of heat.

4. What influence has the temperature of the soil upon the germination of seed? What kind of soil is likely to provide the most favourable temperature for seeds sown in March, and why?

5. What is meant by the terms "early" and "late" soils? Illustrate your answer by comparing two fields, or gardens, that you know.

CHAPTER XIII.

PLANT FOOD IN SOIL.

PRACTICAL WORK.

1. Take up carefully a young cabbage plant, wash the dirt from the roots, and let the latter dip into water coloured red with eosin, or with red ink. Note that the veins, and later the tissue, of the leaf becomes coloured red owing to the absorption by the root of the dissolved colouring matter.

Colour water red with carmine, and see if it is absorbed by the roots of the cabbage plant. Carmine does not dissolve, but is merely suspended in the water as a fine powder. What conclusion do you come to as to the condition of material that can be absorbed by roots?

2. Shake up some good garden soil with a little water. Allow it to settle for a few minutes. Filter the liquid, and evaporate the filtrate to dryness on a watch-glass over steam. Note the residue, consisting of material which has been dissolved out of the soil. Evidently there are soluble substances present in soils. Put the watch-glass aside for Expt. 3.

3. Among the food materials absorbed by the roots are nitrates. Dissolve 0·05 gram of diphenylamine in 100 c.c. of strong sulphuric acid. Put about a teaspoonful of this solution in a white basin, and add one drop of a solution of nitrate of potash made by dissolving a crystal of the latter in about 50 c.c. of water.

The intense blue colour produced indicates the presence of a nitrate. Test a drop of distilled water in the same way.

Now add a little of the diphenylamine solution to the residue left in the watch-glass in Expt. 2. Are nitrates present? In testing for nitrates the solution of diphenylamine in sulphuric acid must be used in large excess.

With the exception of carbon, all the food constituents of plants are obtained from the soil by the roots.

Plant food must be in solution.—If a seedling plant be placed with its roots in water, coloured with a little red ink or with eosin, the veins of the leaves become red. The dissolved colouring matter is absorbed by the roots, and passes in the **transpiration current** to the leaves. If, instead of red ink or eosin, the water is made red with powdered carmine, the leaf veins are not coloured. Unlike the eosin, the carmine does not dissolve, but is merely suspended in the water as a very fine powder, and so does not pass into the plant. Thus we see that only substances in solution can be utilized as food for plants.

Soluble plant food in soil.—If a little soil be well shaken with distilled water, filtered, and the liquid evaporated to dryness, a slight residue will be left. This is the material that has been dissolved out of the soil by the water. Nitrogen is one of the elements the plant obtains from the soil; it is taken up by the roots in the form known as a *nitrate*. By pouring a solution of diphenylamine in sulphuric acid on to the residue left by the soil water, an intense blue colour will be produced. This indicates the presence of nitrates, which have been washed out of the soil by the distilled water.

Food materials which are insoluble in ordinary water may be soluble in the soil water. We saw in Chapter X. how limestone was dissolved by the soil water containing carbon dioxide. Now this gas is given off by the roots during respiration, and is dissolved in the water in immediate contact with the root hairs. Hence this water acts as a

weak acid, and dissolves materials which ordinarily are considered insoluble.

It is possible also that weak vegetable acids may be directly excreted by the root hairs, and assist in dissolving food materials. If a slab of polished marble is placed in the soil within range of the roots, the polish is dissolved off and marks are left where the roots have been in contact.

A popular manure known as basic slag contains plant food which is insoluble in water, but is soluble to a large extent in the soil water. This is especially true of sour, or acid, soils, *e.g.* peaty soils.

Available and dormant plant food.—Only a very small proportion of the food material in the soil is in such a condition that it can be absorbed by the roots of plants. In this condition, food is known as **available** plant food. The much larger store of food material that plants are unable to make use of until it has undergone certain changes in the soil, is termed **dormant** plant food. For example, most of the nitrogen in the soil is in a dormant form, and crops may suffer from nitrogen starvation on soils containing several tons per acre of this element. On such soils, the application of as little as one cwt. per acre of nitrate of soda, supplying only about 17 lbs. of available nitrogen, would greatly improve the crop.

Soils from which crops are removed year after year without having any return made to them in the form of manure become exhausted of available plant food, and cease to grow profitable crops. If the land is **fallowed**, that is, given a rest from cropping for a season and kept well worked, dormant plant food will be made available, and larger crops may again be grown for a time. More commonly, the supply of available plant food is increased by the application of suitable manures.

Manuring.—Of the substances which the plant obtains from the soil, all except three occur in practically all soils

in quantities sufficient for the requirements of crops. The three substances liable to be deficient are: (1) *nitrogen*, (2) *phosphates*, and (3) *potash*, and the chief object of manuring is to supply one or more of these in a readily available form. Sometimes the soil is deficient in all three substances; in other cases it is lacking in one or two only.

Some of the most common manures used by the farmer are:

Nitrate of soda, Sulphate of ammonia,	supplying nitrogen.
Superphosphate, Basic slag,	,, phosphates.
Sulphate of potash, Kainit,	,, potash.
Dissolved bones, Bone meal,	supplying nitrogen and phosphates.
Farm-yard manure, Peruvian guano,	supplying nitrogen, phosphates, and potash.

Pot experiments.—Fig. 41 is a photograph of different kinds of plants grown in pots of sand. The vertical row of pots on the extreme right gets manure supplying nitrogen, phosphates, and potash—all the three substances liable to be deficient in soils. Compare the crops with those growing in the row to the left which receives no manure. The 7th row counting from left to right receives the same manure as the 8th except that potash is omitted. The crops are not quite so good. In the 6th row, phosphates have been left out with the result that the crops are greatly reduced. With the exception of the clover, the crops in the 5th row which receive phosphates and potash but no nitrogen are no better than the "no-manure" crops. Why the clover is so good in this row, we will consider later. The 2nd, 3rd, and 4th rows receive manures supplying one substance only. The crops are all very bad; but the nitrogen has been of most value.

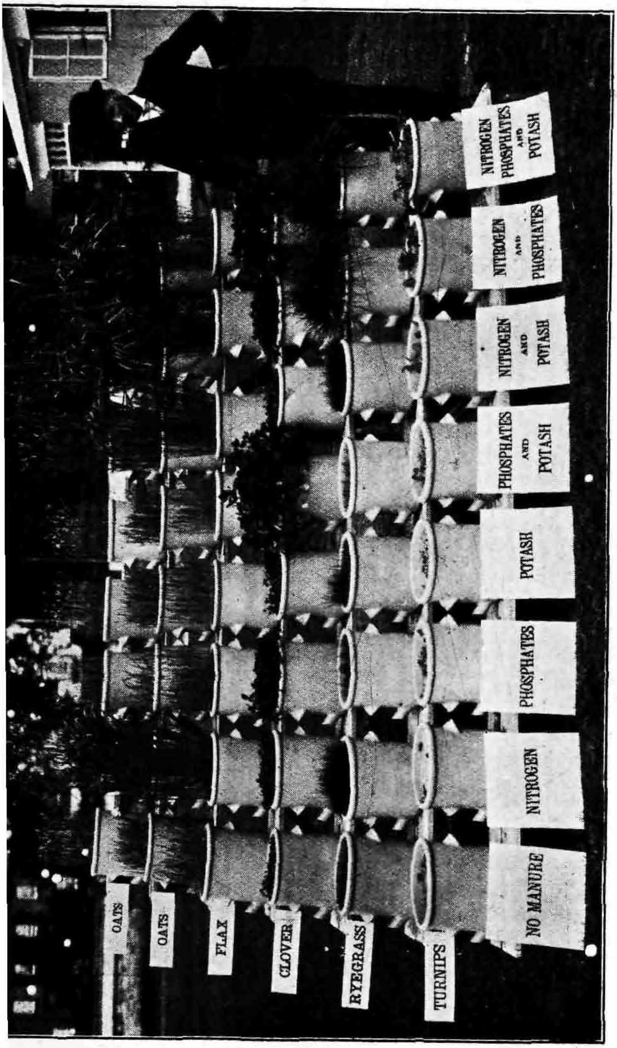


FIG. 41.—Pot experiments, showing influence of manures on crops.

If the soil is deficient in one or more of the three substances, we see the necessity of supplying them in the form of manure if full crops are to be obtained. The farmer often suffers loss because he fails to supply the manure containing the ingredient or ingredients that are deficient in the soil. Perhaps at a time when the crop is languishing for want of nitrogen, he dresses his field with superphosphate although there may be abundance of phosphates already in the soil.

Field experiments.—The best way to find out what substances are deficient in the soil is to treat small plots in the field with different manures just as in the pot experiments described. Agricultural colleges and many county councils carry out experiments of this kind in order to provide information for farmers as to the best manures they should use.

EXERCISES.

PRACTICAL.

1. Mix sulphate of ammonia with lime, or soda lime, in a test-tube. Notice the strong smell of ammonia. What element does this prove the presence of? (See p. 53.) Test dissolved bones in the same way.

2. Fill five good sized plant-pots (say 10 inches diameter) with poor soil. Thoroughly mix up with the soil the following manures per square foot of area of the top of the pots:

(1) No manure.

(2)	Superphosphate	10 grams.
	Sulphate of potash	2 "
	Nitrate of soda	4 "

Apply one-third of the nitrate of soda with the other manures, and the remainder at intervals of about a month, mixing with a little sand and sprinkling over the soil.

(3) Same as 2 but omit the superphosphate.

(4) Same as 2 but omit the sulphate of potash.

(5) Same as 2 but omit the nitrate of soda.

Sow seeds of oats or mustard (the latter will grow quicker) and compare the effects of leaving out of the manurial mixture, phosphates (pot 3), potash (pot 4), and nitrogen (pot 5).

If too thick, thin the plants out when young.

3. To patches of cabbage, grass, oats, etc., apply nitrate of soda at the rate of 15 grams ($\frac{1}{2}$ oz.) per square yard, and compare growth with that of untreated plants.

4. Grow beans in a pot of soil, at the bottom of which a slab of polished marble has been placed. After about 6 weeks examine the marble and see if the roots have corroded the polished surface.

WRITTEN.

1. A sample of soil from the top 9 inches of a field was found to contain 0·15 % of nitrogen. How much nitrogen would be contained in an acre of soil to a depth of 9 inches? (Calculate 1 cubic foot = 90 lbs.)

2. What essential elements of plant food are liable to be deficient in soils? Give examples of manures that would supply these elements.

3. Explain how the farmer may waste money by the misuse of certain manures.

4. What is meant by fallowing a field? What influence has it upon the plant food in the soil?

5. Describe experiments to show that the roots of plants can take in dissolved substances but not solid particles however fine.

6. Describe any experiments to show that the soil contains soluble materials and that similar substances can be found in plants.

CHAPTER XIV.

THE LIVING ORGANISMS IN THE SOIL.

PRACTICAL WORK.

1. Plug the stem of a funnel lightly with cotton-wool, and fill the funnel two-thirds full of good garden soil. Mix with the soil about a teaspoonful of powdered mortar from a wall. Add distilled water to the soil and test for nitrates the first drop that passes through by introducing it into diphenylamine solution (page 107). Note if any nitrates are present.

Wash the soil with distilled water until one drop of the washings gives no blue colour with diphenylamine. The nitrates have then all been washed out of the soil.

Now place the funnel in a dark, warm cupboard. Keep the soil moist and stir occasionally, but do not add so much water that it washes through. After a week or so again wash a little distilled water through the soil, and test the first few drops for nitrates. If nitrates are now present in the soil they must have been formed in the soil since the latter was last washed. If no nitrates have formed, put the soil back into the cupboard and test again after a longer period.

2. In Fig. 41 compare the crops in the row on the extreme right which get nitrogen, phosphates, and potash with those receiving phosphates and potash only. Omitting the nitrogen has had very harmful results on all the crops, except clover. Evidently the clover can do without nitrogen in the soil. Examine the roots of red and white clover, and note the little swellings or nodules on the roots. See if you can find similar nodules on the roots of turnips,

grass, or oats. If not, then it would appear possible that these nodules have something to do with the power of clover to do without nitrogen in the soil.

Examine plants that are related to clover (*e.g.* beans, peas, and vetches), and see if they also have nodules on the roots.

Decay in the soil.—A handful of hay will rot when buried a few inches deep in a tillage field. For a time the stems and leaves will retain their structure, and the material will be recognizable as rotting hay. Later, all resemblance to hay is lost, and the black decaying vegetable matter that we term humus is formed. This humus becomes incorporated with the soil, and finally disappears as completely as if it had been destroyed by fire; only the ash constituents remaining in the soil.

Living organisms in the soil.—Changes such as those described above are due to living organisms present in the soil. Most of the organisms are so minute that they can only be seen with the aid of a very powerful microscope, and so they are called **micro-organisms**, or, more familiarly, *microbes*.

The most important group of micro-organisms in the soil is that known as **bacteria**, of which there may be as many as several millions in one gram of soil. But for the work of bacteria, dead vegetable and animal matter, instead of providing, by its decay, food for new generations of plants, would accumulate in the soil.

Nitrification.—In the previous chapter we learned that nitrogen is one of the elements of plant food likely to be deficient in the soil.

The making available of the nitrogen locked up in buried crop residues and humus is one of the most important results of the decay of organic matter in the soil.

Plants take up practically all their nitrogen in the form of nitrates, *e.g.* nitrate of potash (saltpetre), nitrate of soda, and nitrate of lime. In well-cultivated soils the nitrogen in dead

vegetable and animal matter is converted gradually into ammonia, and finally into nitrates by the agency of certain kinds of soil bacteria. This change is known as **nitrification.** The strong smell of ammonia often found in stables, or rising from manure heaps, is due to this action of bacteria. In the soil the nitrogen in artificial manures, such as sulphate of ammonia, is rapidly converted into nitrates.

The nature of the changes brought about by bacteria in the nitrogen of farm-yard manures and similar materials may be shown as follows. Dilute liquid manure from a stable is put into two small flasks; to each a little chalk and soil are added, and the mouths of the flasks are plugged with cotton-wool. One flask is now heated in a steamer for an hour in order to kill the bacteria present in the liquid. When the bacteria are destroyed, the liquid is said to be **sterile.** Air can get into the flask through the cotton-wool, but the latter acts as a filter and prevents the entrance of bacteria, so that the liquid will remain sterile for any length of time. The flasks are now kept together in a dark, warm cupboard. For a week or two the liquid in the unsterilized flask smells strongly of ammonia. The first stage in the process of nitrification is going on; the organic nitrogen compounds in the manure are being converted into ammonia. Later the smell of ammonia disappears. After 4 to 6 weeks it will be found that the liquid is rich in nitrates, and that there is no ammonia present.

If the plug be now removed from the sterilized flask and the liquid examined, no nitrates will be found. The killing of the bacteria has prevented nitrification. A pinch of soil introduced into the flask will supply the necessary stock of bacteria, and in due course nitrates will be formed. Similar changes may be shown to take place in the soil. A sample of soil washed free from nitrates and kept warm for a week or so will be found to contain nitrates when again washed.

Conditions of nitrification.—The bacteria concerned in forming nitrates only work under certain conditions. The most important of these are: (1) warmth, (2) air, (3) moisture, and (4) the presence in the soil of carbonate of lime.

Nitrification is most active during summer, provided the soil is sufficiently moist, and almost ceases during winter. A sandy soil is especially favourable to nitrification owing to the good air supply. Stirring, because it aerates the soil, promotes nitrification. For this reason horse-hoeing the turnip drills may be equivalent to a small dressing of nitrate of soda. It is the lack of air on water-logged soil that prevents nitrification. Other substances in the soil will serve instead of lime, but in practice this is the one to be considered. Liming the land may increase the supply of available nitrogen by encouraging nitrification.

Under ordinary conditions the nitrates formed do not remain long in the soil, but are either taken up by the roots of plants or washed out by rain. If the washing of the soil by rain be prevented, the nitrates formed accumulate. Much of the nitre used for making gunpowder was at one time obtained by mixing a heap of soil and lime rubbish with urine and similar organic material. The heap was kept moist, warm, and well stirred, and from time to time the nitrate of lime formed in the heap was washed out with water, and afterwards converted into nitrate of potash, or nitre.

How clover gets its nitrogen.—Look again at Fig. 41, and compare the pots receiving phosphates and potash but no nitrogen with the pots getting all three substances. The omission of nitrogen has been very harmful to all the crops except the clover. It appears, then, that the clover can do without nitrogen in the soil. This is not because clover requires no nitrogen; on the contrary, it contains much more than any of the other crops growing in the pots. The non-dependence upon soil nitrogen is due to the fact that

clover and also peas, beans, vetches, and other crops, known as *leguminous* crops, are able to make use of the free nitrogen of the air. They can only do this provided that a particular kind of bacteria is present in the soil.

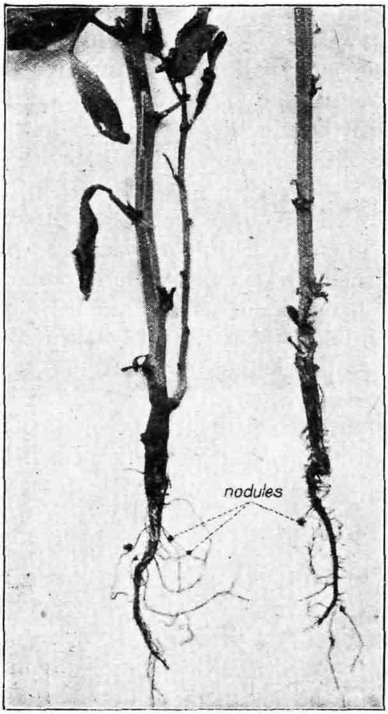


FIG. 42.—Roots of beans showing nodules.

If the roots of clover be examined, small nodules will be seen. The nodules of the bean (Fig. 42) are larger. Each nodule contains enormous numbers of bacteria (Fig. 43) which fix the nitrogen of the air and make it available for the plants

upon which they are living. These bacteria are present in practically all cultivated soils. They enter into the young roots of leguminous plants, causing nodules to develop. From the plant the bacteria obtain part of their food, and in return supply their host with nitrogen. It is a partnership between the bacteria and the plant, and is of great advantage to both. If the bacteria in the soil are killed before the seed is sown and precautions taken to prevent their getting into the soil afterwards, leguminous crops—like other crops—will be dependent upon the nitrogen in the soil. It must be kept in mind that these nitrogen-fixing bacteria are quite different from the nitrifying bacteria which merely change the form of the nitrogen compounds already in the soil.

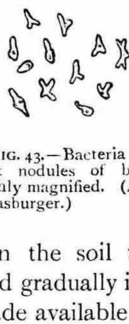


FIG. 43.—Bacteria from root nodules of bean: highly magnified. (After Strasburger.)

Why clover enriches soil.—When the clover crop is cut, or grazed, its roots and stubble are left in the ground. These contain large stores of nitrogen, collected by the plants from the air. In the soil this material decays, and the nitrogen is converted gradually into nitrates by the nitrifying bacteria and so made available for subsequent crops. Hence the growth of clover and similar crops enriches the soil with nitrogen. After clover or beans the farmer usually grows wheat, a crop which obtains its nitrogen from the soil, and so reaps the benefit of the nitrogen collected by the previous crop.

Harmful organisms in soil.—As well as useful soil organisms, such as those discussed above, harmful kinds may be present in the soil, especially if the soil conditions are not favourable to the useful forms. Some cause a loss of nitrogen, others cause disease in plants and animals.

EXERCISES.

PRACTICAL.

1. Obtain a little liquid manure from a stable. Dilute with 50 times its bulk of water, and fill two flasks (about 250 c.c.) one-third full. Add to each about one gram of chalk or of powdered mortar and one gram of soil. Test the liquid for nitrates by adding one drop to diphenylamine solution (page 107). Plug the necks of the flasks with cotton-wool, and sterilize one flask by heating for 1½ hours over boiling water in an ordinary domestic steamer. Keep both flasks in a dark, warm cupboard. Do not move the stopper from the sterilized flask, but smell the liquid in the other flask from time to time, and note the smell of ammonia. In what time does this smell disappear?

After about two weeks remove a drop of the liquid, and test it for nitrates. Test at weekly intervals until one drop produces an intense dark-blue colour with diphenylamine. Now remove the plug from the sterilized flask, and test the contents for nitrates. If it has been properly sterilized, no nitrates will be found. Introduce into this flask a pinch of soil, which will seed it with bacteria, and test for nitrates at weekly intervals.

2. Grow 3 pots of red clover and 3 of oats on poor soil as described on page 112.

Apply per square foot.

(1)	No manure.	
(2)	Basic slag - - - - -	15 grams.
	Sulphate of potash - - -	2 "
(3)	Basic slag - - - - -	15 grams.
	Sulphate of potash - - -	2 "
	Sulphate of ammonia - -	2 "

Mix the sulphate of ammonia with the soil in pot 3 after the other manures have been applied. Basic slag and sulphate of ammonia must not be mixed together before adding to the soil Compare the effects of the nitrogen (in sulphate of ammonia) on clover and oats respectively.

WRITTEN.

1. What is meant by nitrification? What conditions are necessary for nitrification to take place?

2. Whence do leguminous plants, such as clover, obtain their nitrogen? Of what advantage is this to the farmer?

3. Describe an experiment showing what changes take place in liquid manure when applied to the soil.

4. When nitrate of soda is applied to a crop, its effects can usually be seen in a few days; but the nitrogen in farm-yard manure and guano acts much more slowly. Can you explain this?

5. By what practical methods can the farmer cause nitrates to be formed more quickly in the soil?

6. What becomes of the nitrates formed in the soil if there is no crop occupying the ground?

7. The soil has been described as the "living soil." What is meant by this?

8. A good clover crop is regarded as an excellent preparation for the subsequent wheat crop. Explain fully the reason for this.

CHAPTER XV.

SOILS AND CROPS.

In the last few chapters some of the ways in which different soils vary in respect of their supply of air, water, food, and warmth have been discussed. It has been seen also that, to a considerable extent, these soil conditions may be controlled by skilful cultivation and treatment. Thus, by thorough drainage, a wet, cold soil may be made warm and dry; by judicious manuring, the deficiency of any element of plant food may be rectified; and a stiff, impervious clay soil may be made more friable and porous by the application of lime, or by exposure to frost. Similarly, soils which are too dry may have their capacity for holding water increased by direct additions of organic matter.

For all plants, certain conditions as to the supply of air, water, warmth, and food, must be fulfilled; but different plants vary greatly in their requirements. The farmer recognises this when he speaks of "barley soil" or of "wheat land"; for although barley and wheat are often grown on the same field in different seasons, the most profitable crops of each are grown on distinctly different kinds of soil.

Broadly speaking, the art of farming may be said to consist in:

(i) The selection of those crops which are most generally suitable to the soil and climate of each particular farm; and

(ii) Skill and care in the management of the land, so that

the soil conditions may be favourable to the growth of the crops in question.

In the present chapter some points in the cultivation and management of a few of the common farm crops will be considered; and an endeavour will be made to correlate with the most approved farm practice the facts learnt about the growth and habits of plants and the nature of soils.

Arable and pasture land.—Agricultural land is divided into two great classes—**tillage,** or **arable** land; and **pasture** land. The term arable is applied to that portion of the land which is tilled or cultivated; while pasture signifies that part which is not worked with the plough, but is kept down to grass. Arable land is occasionally sown to grass; but in this case the grass remains down for a few years only. To this section of grass land, which is ploughed up again after a short time, the term **temporary pasture** is applied in contradistinction to that of **permanent pasture**, which is used to denote land that is always in grass. Grass land which is cut regularly for hay is spoken of as **meadow land**.

Rotations.—On arable land, the same kind of crop is not usually grown year after year on the same field. For instance, one season there will be a root crop, and the next a corn crop, and so forth. This practice has arisen because past experience has shown that the land becomes less productive when the same crop is grown for some years in succession. Accordingly, the farmer grows his crops in **courses**, or **rotations**, in such a way that any one crop does not, as a rule, occupy the ground more than once in four or five years, or more.

The following example of the well-known Norfolk rotation will illustrate this point. This rotation is:

1st year,	- -	Roots.
2nd ,,	- -	Barley or Oats.
3rd ,,	- -	Seeds—grass or clover.
4th ,,	- -	Wheat.

After the fourth year the cycle is repeated, so that roots follow wheat, and so on.

Almost every district has its own rotation, the particular type being decided by local conditions of soil and climate, and by market facilities. For example, in many districts, the grass seeds are left down for two or three years, instead of for one year only, thus making a five- or six-course rotation.

Regular rotations are followed less rigidly now than was the case some years ago. The farmer has now better implements for cleaning and cultivating his land, and a much larger choice of manures with which to make up any deficiency in plant food in the soil.

Certain crops, usually grown in rotation, may be grown on the same land for many years in succession, if the land is kept free from weeds and suitably manured.

Fig. 44 is a photograph of a crop of barley—the seventeenth grown in succession on the same land. The farmer considered it more profitable to grow barley year after year in this field than to adopt the ordinary rotation. This could not have been done profitably before our present supplies of artificial manures were available; but by applying suitable manures and by cleaning the land in autumn, good crops have always been grown.

Some crops—*e.g.* red clover and turnips—cannot be grown continuously on the same land, however rich and clean the soil may be; they have to be alternated with other crops, and, therefore, must be grown in rotation.

A few of the advantages to be derived from rotations, and some of the reasons for the particular place in the rotation of the common farm crops, will now be indicated.

Root crops.—The chief "root" crops are turnips, mangels, and potatoes. The greater part of the "root" or "bulb" in the case of the mangel and turnip, is a true root; but the potato, as we have seen, is a swollen underground stem.

Before root crops were so largely grown, their place in the rotation was taken by what are known as **bare fallows.** When land is fallowed, no crop is grown; and the land is ploughed and stirred many times during the summer. In this way weeds are killed; dormant plant food is made available; and, owing to alternate wettings and dryings and to changes of temperature, the soil becomes more friable. In the autumn a crop of wheat is sown. Fallowing is an

FIG. 44.—Crop of barley in stooks. The seventeenth in succession on the same field.

excellent preparation for wheat, but very expensive, and is now rarely adopted except on the stiffest clays.

The growing of roots not only provides the opportunity for thoroughly cleaning and cultivating the land, such as is secured in the case of a bare fallow, but also supplies a large amount of winter food for stock.

Swede turnips.—That class of turnip, known as the Swede turnip, is most generally grown, and its cultivation may be regarded as typical of the root crop.

Swedes are grown on a very wide range of soils. A deep,

medium, or sandy, loam is the most suitable; but when well managed excellent crops are grown on clay loam, and on soils that are too shallow for the culture of mangels.

Preparation of land.—Swedes are usually grown after a corn crop. At harvest time the land is often very weedy, and if this is the case the surface is worked with the cultivator, or lightly ploughed as soon as possible after the removal of the corn. The rhizomes of such plants as couch and colt's-foot, and the underground parts of other perennial weeds, are dragged to the surface, collected, and burnt. The shallow cultivation at this time results in the germination of many of the seeds that have been shed by weeds growing among the corn. Subsequently, the young weed seedlings are killed by being buried with the plough, or by exposure on the surface after having been uprooted by tillage implements.

After a heavy corn crop, much less cleaning will be necessary than after a light and thin crop. The heavy crop smothers the weeds and leaves a clean stubble. This may generally be seen when manure has been applied to a portion only of the corn crop; the stubble on the manured part of the field will be comparatively clean, while the unmanured part may be green with weeds.

Whether the land receives this specially early autumn cultivation or not, it is generally ploughed in autumn or early winter. This ploughing should be deep. If it is desired to deepen the soil, now is the best time to do so. In this case, the plough goes a little deeper than the soil proper, and pares off a thin layer of the subsoil, which is turned to the top. The subsoil, which might be very injurious to the crop if brought to the surface immediately before sowing, is exposed on the surface to the weather during winter, and becomes mellowed into useful soil before sowing time.

It is because of the weathering effects of exposure during

winter that early ploughing is much more important for stiff clay soils than for sandy soils. When land is ploughed up and left rough during the winter, the frost shatters the clods, and flocculates the clay particles, so that a fine, crumby seed bed is easily obtained at seed time.

In spring, the ploughed land is worked with such implements as the grubber or cultivator, the harrow, and the roller. All these implements pulverise the soil, until a good depth of loose, fine soil is obtained. The less working the land requires at this time the better. Frequent stirring in dry weather soon dries the soil, so that the top few inches of soil may not contain enough moisture for the rapid germination of the seed and the growth of the young plant. Later in the season, when the roots of the swede are getting their water supply from the deeper parts of the soil, frequent stirring of the surface will do good by preventing loss of water from the soil below.

None of the tillage operations described should be carried on when the land is wet, or it will become puddled. The damage done in this way is greatest with spring cultivation, because there is then no opportunity of correcting the puddled condition by exposure to the frosts of winter.

In passing from a wet to a dry condition, soils reach a stage of dryness when the lumps easily crumble with pressure. If the soil is worked before this stage is reached, puddling will result, and, on subsequent drying, the land will set hard. It will only be after long exposure that the soil will break down into that desirable condition known as **good tilth**. On the other hand, if the land is allowed to get too dry before being worked, it may set so hard that ordinary tillage implements cannot break up the clods. In this case, however, the damage is only temporary; the clods are not nearly so hard as those formed on the drying of clay that has been puddled, and they break down readily enough after rain.

Sowing of seed.—In Ireland, Scotland, and the North of England, the swedes are sown on ridges. In the South of England, where the climate is drier and warmer, the ridges would be liable to become too hot and dry for satisfactory growth, and so the seed is sown on the flat.

Swede seed is small, and therefore shallow sowing is necessary. If the surface is dry enough, the soil is usually rolled after the seed is sown. This rolling brings the soil particles close together, makes the channels between them small, and so causes water to be raised by capillarity, so as to provide for germination and to supply the seedling during its earlier stages of growth. When the soil is rough and lumpy, it soon dries and the seed may not germinate until rain falls. But should germination take place, the seedlings may die from lack of water before their roots can reach the moist layers of soil. It is most important, therefore, in this stage of the plant's life, that the soil immediately below the surface should be moist; yet, it must not be so wet as to become puddled by the treading of the horses, or the pressure of the roller.

Manuring.—The swede crop is invariably manured. It utilises to a smaller extent than most other crops the store of plant food already in the soil. On soils containing sufficient plant food to grow a good crop of corn, the turnip crop may be a failure for want of manure. This is shown in Fig. 45, which is a photograph of swedes grown on experimental plots manured in different ways. The soil is a sandy loam: the rough mechanical analysis of this soil is given on page 75. It is an excellent turnip soil for the climate of the district in which it is situated.

The land would have grown a good crop of oats without the application of any manure to the soil, yet the turnip crop was only 7 tons per acre. The supply of water, warmth, and air in the soil has been sufficient—when the small dressing of 10 tons per acre of farmyard manure was given—to

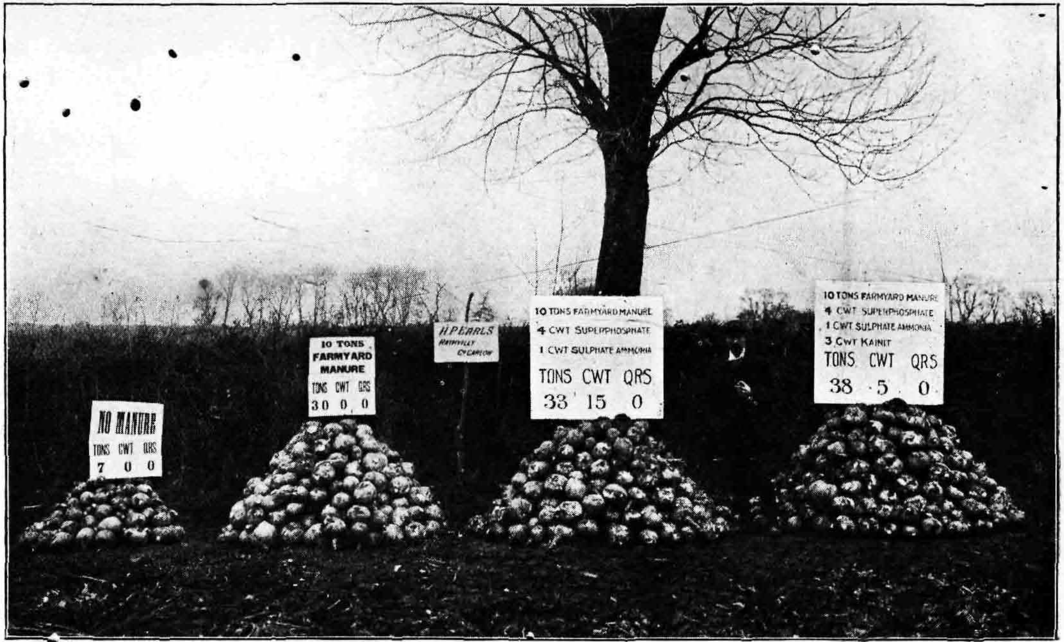
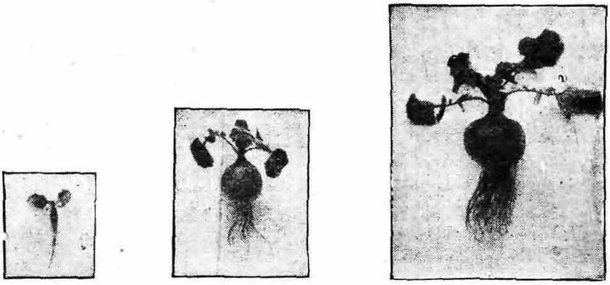


FIG. 45.—Showing results of an experiment on the manuring of swede turnips.

grow a crop of 30 tons per acre. This amount of manure, however, has evidently not supplied sufficient food to enable the plant to take full advantage of the other good conditions for growth; for, where certain artificial manures have been applied, in addition to farmyard manure, the unusually good crop of over 38 tons per acre has been grown.

When available, farmyard manure is generally applied to the swede crop. Not only does this manure supply plant



Grown without manure. — Grown with manure supplying phosphates and potash. — Grown with manure supplying phosphates, potash, and nitrogen.

FIG. 46.—These turnips were grown on adjacent plots. The specimens illustrate the importance of using on this soil manures supplying all the three substances liable to be deficient. (By kind permission of the Royal Agricultural Society of England.)

food, but it adds humus to the soil, and so has an important influence on its physical character. Thus, farmyard manure makes light, sandy soil more retentive of moisture; while on stiff, clay land it opens up the soil, making it more porous and easier to cultivate.

In addition to farmyard manure, some **artificial manure** is generally given. The substance that turnips are most likely to be in need of is **phosphate**; accordingly, 3 to 5 cwt. per acre of superphosphate, or basic slag, is applied in addition to farmyard manure. Where no farmyard manure is used, it is almost always necessary to supply nitrogen and potash, as well as phosphates, in the artificial manures given.

The importance of supplying all the three substances under these circumstances is illustrated in Fig. 46.

Summer cultivation.—After germination the seed-leaves of the swede come above ground, and are known as the **smooth leaves**. At this stage the crop is very liable to be attacked by the turnip flea-beetle, which eats the leaves, and often so badly as to kill the plant. The best way of preventing the destruction of the crop in this way is to have the soil fine and moist, and well supplied with readily available plant food, so that growth is quick and the ordinary, or rough, leaves are developed before the seed leaves are destroyed.

When the plants have become established it is no longer necessary for the soil to be kept moist near the surface. We have seen that a rolled surface is wasteful of water, and as there is usually very little rain at this time of the year, it is important to save as much as possible of the water in the subsoil for the use of the crop. The horse hoe is therefore worked between the ridges, or rows, of swedes to loosen the soil and form a mulch (p. 97), which will reduce the loss of water by evaporation. This hoeing also kills any weeds that may have sprung up between the rows of turnips. When the leaves are about 2 inches across, the swedes are **thinned**, or singled, so as to leave single plants every 8 or 10 inches. This operation is usually done with the hand hoe, which, at the same time, chops out the weeds and loosens the soil where the horse hoe has not reached.

During the summer the horse hoe is worked frequently between the drills. Besides destroying weeds and keeping a mulch of loose soil on the surface, the stirring of the soil promotes nitrification, chiefly because of the freer circulation of air in the soil. Even when there are no weeds, the top 2 or 3 inches of soil between the drills should be kept loose by horse hoeing, until the leaves extend so far across the drills that the horse cannot walk along the rows without

injuring the plants. Good turnip crops cannot be grown when the ground is allowed to become hard.

Seed growing.—The swede is a biennial plant. During its first season the stem remains short, and the material manufactured in the leaves is stored in the root. If allowed to grow the following season, this reserve food is used up in the production of seed. When the farmer wishes to raise his own turnip seed, selected roots are pulled and stored until the following February, and then transplanted in good soil. During the summer the stem lengthens and bears numerous flowering branches. About July the stems are cut, and after lying for a few weeks the ripe seed is thrashed out. Very few farmers raise their own turnip seed, and in any case the bulk of the crop is used for stock-feeding. In November or December the season's growth is completed, and the roots are pulled, "topped," and "tailed," and stored in pits or clamps until required for feeding.

Sheep folding.—On sandy or light land the swedes are often "fed" to sheep on the field where grown. The manure made by the sheep enriches the land for the subsequent crops of the rotation, and the treading of the sheep consolidates the land and improves its water-holding capacity. The folding of sheep in this way on clay soils, however, would be injurious to the land and, usually, harmful to the sheep. Owing to the treading of the sheep on the wet soil the clay would become puddled, and, when ploughed up later, would dry into hard clods, and it would be impossible to break them down into a fine tilth for the subsequent barley crop.

Finger-and-toe.—The swede is very liable to suffer from a disease known as **finger-and-toe** or **club-root**. This disease is caused by one of the harmful organisms so often present in soils. This organism is a very minute *fungus*, and it enters the root through the root hairs. Within the plant the fungus feeds and increases in size at the expense of the

food material in the roots, and causes the latter to become distorted and swollen (Fig. 47). In some cases nearly all the plants in the field are killed by this disease, and the roots rot away. In other cases the attack is less severe in itself, or the plants are healthier and so better able to resist the disease.

The finger-and-toe fungus may live in the soil for many years, but it only attacks plants belonging to the same family

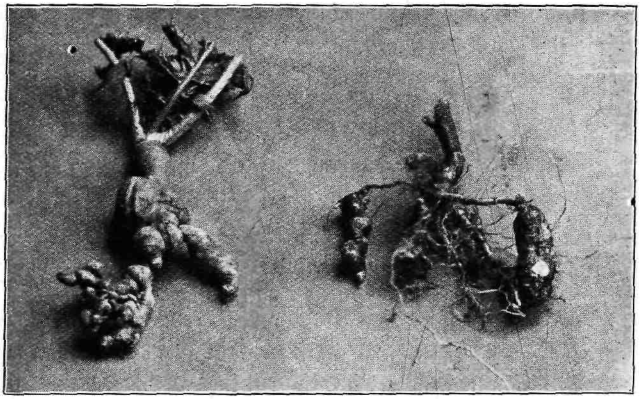


FIG. 47.—Roots affected with finger-and-toe disease: turnip root on the left; root of charlock on the right.

as the turnip—*e.g.* cabbage and charlock—and the fungus is starved out if crops of this kind are not grown for some years. A root of charlock affected with finger-and-toe is shown in Fig. 47. Unless this weed is eradicated, finger-and-toe cannot be starved out of the land. With the object of freeing the land from this pest, mangels or potatoes are often grown instead of turnips as the root crop in the rotation.

Unlike the nitrifying bacteria, the finger-and-toe organism thrives best in sour soils, and dislikes lime in the soil. The

best preventive of the disease therefore is lime, which should be applied some time before the crop is sown, so that it may become thoroughly incorporated with the soil.

Liming of land.—Besides preventing finger-and-toe, the application of lime is beneficial in other ways to soils that are deficient in this constituent. Some of the effects of liming have been dealt with in previous chapters. The influence of lime on the soil lasts for many years, but as it is often applied when the land is being prepared for roots, or after the roots have been removed, it will be convenient to summarize here its chief effects on arable land.

(1) On stiff clay soil, lime flocculates the fine clay particles. The soil becomes more friable and easily tilled. The danger of puddling is reduced, and water passes through the soil more quickly, and so allows access of fresh air into the soil.

(2) Lime assists the decay of vegetable matter in the soil, and encourages nitrification; this is partly owing to the reasons stated in (1), and partly because lime is necessary for the work of the nitrifying bacteria.

(3) Besides liberating plant food by hastening the decay of organic matter in the soil, lime acts upon the dormant potash and phosphates in the soil, and makes them available.

(4) Lime prevents finger-and-toe in turnips.

(5) Lime supplies to the soil an essential element of plant food; but, considered from this point of view, the direct application of lime is rarely necessary, as practically all soils contain sufficient lime for plant nutrition.

Although the effect of lime is generally so beneficial, it must be remembered that it does not supply nitrogen, phosphates, and potash to the soil; but it brings into use the locked-up stores of these substances already present. So

that, unless manure is also applied, the ultimate effect of lime will be to exhaust the soil.

There is an old saw which runs :

> "Lime and lime without manure
> Will make both farm and farmer poor."

Barley.—The best soil for barley contains a large proportion of sand and only a small amount of clay. Such a soil is dry, warm, and easily worked. Heavy crops may be grown on clay loams, but the best quality of grain is produced only on the lighter classes of soil. In a wet climate and on clay soils the straw is usually long, weak, and liable to lodge, and the grain is coarse and of little value for malting purposes.

Preparation of seed bed.—Barley usually follows a root crop. After the roots have been removed, the land is ploughed and subsequently harrowed and cultivated, until an especially fine seed bed is obtained. As barley is shallow-rooted, it is not necessary for the cultivation to be deep. A fine seed bed is much more necessary for barley than for oats; and care must be taken not to attempt to work the stiffer soils until the soil is sufficiently dry to prevent puddling. The best barley soils may be worked in almost any state.

Seeding.—In order to get a good sample of malting barley, it is important that the crop should ripen evenly. When the crop in its early stages is thin, the young plants tiller freely, and the younger branches, or tillers, may be several weeks younger than the parent stem. The result is that some of the ears are ripe much sooner than others. When the thinness of the crop is due to sowing seeds of poor germination, the loss could have been prevented by first testing the seeds, as described in Chapter II., and so finding out if more seed than usual should be sown. Unevenness of ripening is often due to insect attack—*e.g.* that of wireworm. Many of the plants are killed, and those remaining

are encouraged to tiller, owing to the extra amount of space and the increased share of food.

Evenness of ripening is of much less importance in the case of wheat and oats.

Manuring.—As barley is usually grown after a highly manured root crop, it is rarely manured directly. Sometimes phosphates and potash are applied, with a view chiefly of strengthening the straw and improving the quality of the grain. Manures supplying nitrogen must be used sparingly, or the crop will be liable to lodge, and late in ripening.

Clover.—After barley, clover alone, or a mixture of clover and grasses—known as "seeds," or "rotation grasses"—is usually taken. The seed is sown broadcast on the surface, either shortly after the barley has been sown or when the latter is a few inches high. By means of a light harrow, the seed is covered with a little soil, and then well rolled in order to draw water to the surface from below.

Barley straw is short, and under ordinary conditions allows sufficient light to reach the young clover and grass plants; at the same time the seedlings are protected from the effects of excessive transpiration. When the barley is cut, the clover or "seeds" should be well established and should cover the ground evenly. If the corn crop is thin, and especially in wet seasons, the conditions are exceptionally favourable for the clover, which grows vigorously and interferes greatly with the harvesting of the barley. On the other hand, the clover may be smothered if the soil is so rich that the corn becomes lodged. Patches of clover may also be killed if the stooks, or shocks of barley, have stood a long time in the field. This is most likely to happen in a wet harvest, but can be prevented by moving the stooks to fresh ground occasionally.

Manuring.—As clover is able to obtain its nitrogen from the air, this crop is independent of the supply of nitrogen in the soil; phosphates and potash are therefore the only substances in which the soil is likely to be deficient, and these

might be supplied, if necessary, by a dressing of superphosphate and kainit in spring, or kainit and basic slag in November.

It is possible that the nitrogen-fixing bacteria, which give rise to the nodules on the clover roots, may not be present in certain poor soils. In this case the clover will need to be supplied with nitrogen in the manure; or the soil may be seeded with the necessary bacteria. This may be done by distributing over the field a few loads of soil from a field which grows clover well, and therefore contains the required organisms. Preparations of the bacteria are also sold under such names as "nitro-bacterine," and successful results may sometimes be obtained by their use. Soils requiring treatment of this kind, however, are very uncommon.

When the "seeds" consist of grasses as well as clovers, as is generally the case in the North of Britain and in Ireland, it may be necessary to supply nitrogen as well as phosphates and potash. Should the grasses predominate, or the crop consist of grasses alone, nitrogen is the most important substance to apply if a bulky crop of hay is desired.

In spring the "seeds" are rolled. This presses back into the soil any plant roots that have been partially lifted out of the soil by the freezing of the soil water and its subsequent expansion, and makes the soil firm about the roots of the plants. A firm soil is very necessary for the growth of clover. The best growth in the field is generally seen on the headlands where the traffic has made the land unusually firm.

Wheat.—This crop requires a firm moist soil and a hot ripening period. A deep clay loam, or a clay soil, is generally well adapted for wheat, and the best crops are obtained in a dry summer. When the top few inches of soil become dry, the deeper layers of a clay soil are cool and moist, and the roots of wheat, extending much deeper than those of oats or barley, keep the plant supplied with sufficient moisture.

Preparation of seed bed.—In the Norfolk rotation, wheat follows clover. The clover is ploughed up as soon as possible after the crop has been cut, or eaten off. This early ploughing is important. It hastens the decay of the clover roots and stubble, so that they become partly converted into humus before the wheat is sown, and also allows time for the soil to settle and become firm before sowing time. In some rotations wheat is grown after roots.

The seed is sown generally in October or November. Wheat requires a seed bed which is sufficiently loose on the top to cover the seed to the required depth, but which is very firm below; and all the tillage operations are designed with the object of securing these special soil conditions. For example, after clover the ploughed land is rolled, or the furrows consolidated with a drill presser; where wheat is grown after roots only a shallow ploughing is given, so that the soil is not stirred to a greater depth than 4 or 5 inches. On the lighter soils it is better to sow the seed when the land is somewhat wet. The clay present in such soils, by being worked in a wet condition, becomes much more effective in binding the coarser particles together, and so the soil becomes less open and better adapted to the growth of wheat. The large proportion of sand present in the light soil prevents it from becoming puddled.

After the seed is sown, the soil is left somewhat rough and lumpy; for if worked until fine, it might become puddled by the winter's rain, and a hard cake or cap would be formed on the surface by the drying action of the sun and wind in spring. This hard crust is known as a **winter cap.** The clods protect the young wheat plants during winter, and crumble down easily when the land is rolled in spring.

Seeding and early growth.—Unless wheat sowing is delayed until December or late in November, the soil will usually be sufficiently warm for satisfactory germination. By the time the shoot appears the weather is generally cold,

and in ordinary seasons the wheat plants appear to make little or no growth until the warmer days of spring. The roots, however, are growing, and upon the development of a good root system in winter largely depends the future vigour of the crop. In a wet winter, on clay land, the soil is liable to be kept so saturated with water that the air supply to the roots is interfered with and healthy root growth cannot take place.

In early spring the crop may look very thin, but the plants soon commence to tiller freely, each giving rise to several new stems by the branching of the parent stem. If the crop is thick or the land poor, less tillering takes place. It is because of the vigorous tillering of autumn-sown wheat, compared with wheat sown in spring, that so much less seed of the former is required. As in the case of barley, the younger tillers ripen a little later than the parent stems, but evenness of ripening is of much less importance with wheat.

When the land is dry enough in spring, the wheat is harrowed and rolled. Harrowing kills many of the weeds, promotes tillering, and breaks down any clods that may be present. By rolling, the land is consolidated, and any plants that have been loosened and partly uprooted by the frosts of winter are again brought into intimate contact with the soil. Occasionally also the land is horse hoed in the spring.

No summer cultivation is possible, and so the advantages derived from stirring the soil during the summer, which we noticed in the case of swedes, cannot be secured in the case of wheat.

Manuring.—The deep roots and prolonged growing period of wheat enable this crop to make better use of the store of phosphates and potash in the soil than most farm crops. The case of nitrogen is different. During winter any nitrates formed in autumn, if not taken up by the crop, will be washed out of the soil. There may be

ample supply of nitrogen in the clover roots, or in the farmyard manure which has been supplied either directly or to the previous crop, but it is of no use until changed into nitrates. The soil cannot be stirred during summer as is the case with root crops, so that, owing to lack of air, nitrification goes on very slowly. Accordingly a manure such as nitrate of soda, supplying available nitrogen, is most likely to be necessary. This should be distributed broadcast over the wheat in spring at the rate of 1 to 2 cwt. per acre.

Ripening.—Wheat is an annual; it grows from seed, produces seed, and then dies down in one year. Flowering and fertilisation take place about June or July. After fertilisation the food material, which is temporarily stored in the leaves and stems, is transferred gradually to the developing seed. That this process is taking place is indicated by the swelling and hardening of the grain and the gradual bleaching of the stem, which eventually assumes that hardness and lightness of colour which is characteristic of the straw.

Wheat is cut before it is dead ripe. It is ready for cutting when the grain no longer gives a milky juice when pressed between the fingers. Further ripening changes take place in the stook and stack.

Wheat has the longest period of growth of all the farm plants, nine or ten months being as a rule necessary for this plant to complete its life history.

Permanent pasture.—The grasses and clovers comprising the herbage of good pastures require a soil that is moist near the surface, yet not so wet as to affect the air supply. A hot dry summer, which is generally very favourable to the growth of the deep-rooted wheat, is harmful to pasture grasses, which are mostly shallow rooted. Although so susceptible to drought, the pasture grasses can stand cold. The best conditions for permanent pasture are therefore:

(1) A cool, moist climate which will reduce the loss of

water by transpiration from the leaves, and also prevent the rapid drying of the soil by evaporation; and

(2) A well-drained deep clay loam, or an alluvial soil, which will retain near the surface a good deal of the water that falls upon it, and also raise water from below with sufficient freedom to keep the soil moist during spells of dry weather.

If, in addition, the soil is also rich in plant food, we get good pastures and heavy crops of hay.

The largest proportion of pasture land is found in the west of Great Britain and in Ireland, where the rainfall is comparatively heavy. The hotter and drier climate of the east and south-east of England is better adapted for corn growing than for grass; and on the farms in these districts there is generally more arable than pasture land.

Most of the inferior pasture land suffers because of a deficient water supply. Except in the wettest climate, sandy and light loam soils retain too little water for the growth of good permanent grass.

On such soils the herbage consists mainly of grasses with small or narrow leaves. These grasses transpire much less than the large broad-leaved grasses found on moister soils, and so are able to thrive when broad-leaved grasses would perish from lack of water.

Little can be done to improve pastures when the soil is so light that the supply of water limits the growth of the more nutritious grasses, for there is no practical method of permanently increasing the water-holding and water-lifting capacity of soils of this character.

In sowing light soils down to pasture, it is found advisable to include in the seeds' mixture a proportion of certain plants, such as burnet, chicory, kidney vetch, lucerne, etc., which are of such a deep-rooting habit as to be independent of the water in the surface of the soil.

On stiff clay soils also, deep-rooted plants are sometimes

included in the seeds' mixture for the purpose of opening up the soil so as to improve the air supply.

Draining.—Soils which suffer from excess of water are usually more amenable to treatment than soils which are too dry. Except in dry seasons, water-logged soils have their pore space a little below the surface filled with water, and good grasses cannot live owing to the deficient air supply. Only certain worthless plants thrive on these soils. Rushes are usually very prominent and may be regarded as a sure indication of an excess of water.

Excessively wet soils can be improved by drainage, which is carried out usually in the following manner. A series of trenches, all having a gentle slope in the same direction, are dug in the field at regular distances apart. At the bottom of these trenches, porous earthenware tiles or pipes are carefully laid, and the earth replaced in the trenches. The excess of water from the soil above, and from some distance on each side of, the line of pipes flows into the drains and is replaced by air.

It is important to notice that by draining only the excess of water is removed, so that a drained soil may be quite moist, in which case there will be air in the larger pore spaces and water in the finer channels and around the soil particles. As water is removed by evaporation from the surface, or absorbed by plant roots, a further supply may be raised from the soil below by capillarity.

The admission of air into the soil by drainage not only provides for the respiration of plant roots but influences the soil in other ways. The soil becomes warmer because water is got rid of by the drains instead of by evaporation, nitrification is promoted because of the better air supply, and any poisonous substances that have accumulated in the water-logged soil are destroyed. Further, on stiff clay soils, weathering changes similar to those which take place on the surface occur in the deeper parts of the soil, so that intract-

able soils become more friable and generally better adapted for the development of a vigorous root system.

After a water-logged soil has been drained, the rushes and other worthless plants that indicate the presence of stagnant water gradually disappear, and are replaced by useful grasses and clovers.

Manuring.—There is a large area of pasture land that is well supplied with air and water, and yet is decidedly inferior owing to the lack of available plant food. When this is the case the defect can be remedied by the application of suitable manures. The application of nitrogenous manures to grass land generally encourages the growth of the larger and coarser grasses, while phosphates and potash promote the growth of the clovers and finer grasses. On clay soils, phosphates are usually deficient. In recent years a large amount of land of this kind has been improved by the application of phosphatic manures—*e.g.* superphosphate or basic slag. After such manures have been applied, the worthless grasses generally found on poor clay land are replaced by a strong growth of white clover which has much greater feeding value.

For example, at the Cockle Park Experiment Station, part of a field of this character was dressed with 10 cwt. per acre of basic slag. Another plot of the same size was left undressed, and for the following five years sheep were grazed on each plot. At regular intervals the sheep were weighed. The total live-weight increase of the several lots of sheep fed on the untreated plot was 205 lbs. per acre, while on the manured plot the sheep increased in weight by 695 lbs. In the five years the profit from the use of the slag was estimated at £6 5s. per acre.

On the lighter classes of soil, potash as well as phosphate is often deficient, and, if not too dry, these soils are improved by the application of superphosphate and kainit, or, basic slag and kainit. The strong growth of clover which

generally follows the use of these manures on both classes of land usually becomes less prominent after a few years. In the meantime, however, the clover plants have accumulated in their roots large stores of nitrogen which has been obtained from the air. When the clover plants die the soil is enriched with nitrogen, and this subsequently becomes available as food for the grasses.

The fertility of the better class of soils is best maintained by the occasional application of farmyard manure, or by feeding corn or cake to stock grazing the pastures. The manure produced by the stock receiving cake is richer than if the stock were fed on grass only, and thus the store of plant food in the soil is increased.

EXERCISES.

WRITTEN.

1. Explain why root crops should be frequently horse-hoed.

2. There is an old saying that "Lime makes a rich father, but a poor son." What is meant by this? State briefly the advantages of applying lime to land.

3. What is meant by rotation of crops? Give an example of a common rotation, or one that is adopted in your district.

4. What substances are most likely to be deficient in the soil for the growth of good crops of (*a*) clover, (*b*) swedes, (*c*) wheat, and (*d*) pasture on clay soil?

5. What is the cause of "finger-and-toe" disease in turnips? How may it be prevented?

6. Discuss briefly the methods of improving pastures that are inferior owing to (*a*) excess of water, (*b*) deficiency of plant food, or (*c*) lack of moisture.

7. What conditions of soil and climate are most favourable for wheat growing?

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